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THE EFFECT OF ISOKINETIC TRAINING ON THE FORCE-VELOCITY RELATIONSHIP AND MAXIMAL POWER IN FEMALE FOREARM FLEXOR MUSCLES

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled . . THE EFFECT OF . . . . ISOKINETIC TRAINING ON THE FORCE-VELOCITY RELATIONSHIP . . AND MAXIMAL POWER IN FEMALE FOREARM FLEXOR MUSCLES . . . . submitted by . . BRIAN C. JONES . . . . in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Physical Education.

ABSTRACT

Forty-two female volunteers (18-29 years) were divided into 6 groups based upon their maximum force generated at peak power. Experimental groups were classified into 2 high (Hi) and 2 low (Lo) force groups while two groups acted as controls. The Hi and Lo training groups were each assigned to a differential 5 week isokinetic training program of 30 and 60% maximum isometric force (P_o). At pretest, the force exerted at peak power was significantly ($p < .05$) different between the Hi and Lo force group.

The training revealed a significant ($p < .05$) main effect for the maximal force production at isokinetic velocities of 90, 150, 210, 270 and 300°/s. At 90 and 150°/s, the rate of force change was significantly ($p < .05$) faster in the Lo force group. In addition, the isokinetic training stimulus of 60% provided a significantly ($p < .05$) faster rate of force change. At 210°/s, both the 30 and 60% training stimuli caused significant ($p < .05$) improvement compared to the control. At 270 and 300°/s, both the Hi and Lo force training groups showed a better response to the 30% training stimulus.

Training resulted in a significant ($p < .05$) improvement in the generation of peak power. In addition, the maximal force exerted at peak power declined significantly ($p < .05$) with the 30% training stimulus providing a significantly ($p < .05$) faster rate of decline compared to the 60% training stimulus as well as the control. Further, the 30% training stimulus was significantly ($p < .05$) different from the 60% at post-test. The Lo 60 P_o training group increased both the maximal force and velocity at peak power by a better "all round" shift in the force-velocity curve.

A significant ($p < .05$) increase occurred in the maximal velocity at peak power at post-test and both training stimuli were significantly ($p < .05$) different to the control.

Maximal isometric force increased significantly ($p < .05$) only at an elbow angle of 100 degrees.

Examination of the pre to post-test alterations in the composite force-velocity-power relationships revealed little displacement in the Hi and Lo control groups. However, the composite curves of the training groups revealed that the 60% training stimulus is more effective in displacing the force-velocity curve "all round" regardless of the Hi and Lo classification and should be used for athletic events that demand velocities of movement within the 90 to 210°/s range. If velocities in excess of 210°/s are required up to a maximum of 300°/s, then the 30% training is more effective. If the objective is simply to increase the peak power then a differential training stimulus is indicated for the Hi and Lo force generators (30 and 60% respectively).

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

The force-velocity relationship has revealed one of the most important dynamic properties of contracting muscle. When a muscle or group of muscles performs a series of single maximal voluntary contractions against a series of increasing loads, the maximal exerted force increases while the maximal velocity of contraction decreases (90). The converse is also true. When the load on the muscle is decreased, the maximal exerted force decreases while the maximal velocity of contraction increases. If corresponding maximal force and velocity values, obtained from single maximal voluntary contractions for a series of decreasing loads are plotted on a Y-X system of co-ordinates, the force-velocity relationship is expressed as a curve (37). In addition, the measurement of maximal isometric force (P_o) and the maximal velocity of contraction under unloaded conditions (V_{max}) have provided further experimental points at the extreme ends of the curve.

Hill (36) fostered the belief in his early research on human arm movements that the reason for the decrease in maximal exerted force as the velocity of contraction increased was that more energy was being used to overcome the increased viscosity of the muscle at the higher velocities of contraction. Many initial investigations into the force-velocity relationship followed this line of reasoning (26,28,30,36,38,61,62).

It was not until Fenn and Marsh (22) concluded unequivocally that the inverse relationship between the maximal exerted force and the maximal velocity of contraction was exponential rather than linear was viscosity eliminated as being solely responsible. This conclusion was re-affirmed by Hill (34) who proposed a "characteristic equation" to describe the nature of the force-velocity relationship of contracting muscle. Research has confirmed that for isolated striated muscle (2,51) as well as intact human muscle (79,90), experimental force-velocity data can be fitted to the curve predicted from Hill's "characteristic equation".

The diminution of force as the velocity of contraction is allowed to increase is now believed to be related to the cross-bridges of the muscle myofilaments. As the actin filaments are allowed to move faster they become less capable of making the cross-bridge connections with the globular heads of the heavy meromyosin molecules. Consequently, the force generation is decreased (10,42,50).

For both isolated striated muscle (33) and intact human muscle (43), one extremely important practical consequence of the force-velocity relationship is that the peak maximal mechanical power output is produced when the exerted force is approximately one-third of the maximal isometric force (P_o), and the velocity of contraction is approximately one-third of the maximal velocity of contraction under unloaded conditions (V_{max}).

Many athletic events demand explosive actions in which the maximal force exerted by the muscles must be transformed to mechanical power by combining with the maximal velocity of contraction.

Interindividual variation in maximal mechanical power output (MMPO) has been shown to be reflected by existing individual differences in the relative position of the force-velocity curve (55,56). Therefore, continued investigation into the alteration of the force-velocity relationship by new and unique training methods is extremely important to the physical educator and coach.

The Problem

The data available, seems to indicate that both the maximal training force exerted by the muscles (43) and the maximal training velocity of contraction (70) must be considered for "all round" alteration of force-velocity curves. This evidence suggests that an optimal training interaction exists between the maximal training force exerted by the muscle and the maximal training velocity of contraction in order to provide the most effective alteration of the curve and consequently the greatest improvement in MMPO. With this in mind, the primary purpose of the present investigation was to evaluate the effects of two different force-velocity training interactions on alteration of the force-velocity relationship and peak MMPO in the female forearm flexor muscles.

In addition, there is recent evidence (52) that the increase in peak MMPO by training is mainly due to an increase in the maximal exerted force at peak MMPO with little increase in the maximal velocity of contraction. This is contrary to an initial investigation (43) reporting concomittant increases in both factors. The possibility exists that the optimal training interaction may have to be modified for individuals who possess different initial levels of maximal exerted force at peak MMPO, in order to place emphasis upon the improve-

ment of either the force or velocity factor under loaded conditions. This hypothesis is strengthened by the fact that individuals can produce identical peak power but with a different combination of the force-velocity factors (56). Therefore, a sub-purpose of this investigation was to evaluate the effects of the two different training interactions on the maximal force and velocity exerted at peak MMPO in individuals who possess different initial levels of maximal force at peak MMPO.

Delimitations of the Study

(1) The study involved 60 female volunteers obtained from the University of Alberta. Their ages ranged from 18 to 29 years.

Assumptions

(1) It was assumed that time and velocity of movement of the forearm were independent variables as the velocity of movement was controlled by means of an isokinetic dynamometer (Cybex II).

Definition of Terms

Maximal Isometric Force (P_o). The maximal force (kg) exerted by a muscular contraction in which length of the muscle does not change appreciably.

Maximal Velocity of Contraction (V_{max}). The maximal angular velocity of movement (degrees/sec) of the forearm produced by the contracting forearm flexor muscles converted to a linear equivalent (meters/sec) without any external load on the muscle.

Maximal Mechanical Power Output (MMPO). The maximal mechanical power output (kgm/sec) as calculated from the product of force (kg) multiplied by the maximal velocity of contraction (m/sec) obtained from the "best fit" force-velocity curves.

Isokinetic Exercise. Maximal force production of a muscle or group of muscles throughout the entire range of motion at a controlled speed of contraction.

CHAPTER II

REVIEW OF LITERATURE

The literature relating to the force-velocity relationship was reviewed under two headings; (1) isolated striated muscle and (2) intact human muscle. In some instances, reference is made from one area to another because both have contributed to the development of the force-velocity relationship as it is understood today.

The Force-Velocity Relationship

(1) Isolated Striated Muscle

In 1920, Hill (35) described a useful inertia device as an instrument for recording the maximum work done in a frog muscle during muscular contraction. The recording system suggested by Hill and employed and described fully by Doi (18) consisted of an arm balanced on knife edges carrying two balanced masses. The rate at which the muscular contraction occurred could be varied by changing the point of attachment of the muscle or the distance of the balanced masses of the system.

Gasser and Hill (26) used the system designed by Hill on the sartorius muscle of the frog to show the relation between the speed of shortening of a muscle to its ability to perform external work. The muscles were allowed to attain their maximum in an isometric tetanus before being released and were then allowed to shorten between two fixed points. An effect was obtained equivalent to allowing the muscle to pull against a wide range of freely suspended masses. The results indicated that the work performed decreased as the speed of shortening increased. To the investigators, the curves relating work to speed of shortening did not appear linear.

Gasser and Hill (26) then used two methods to show the effects of the speed of shortening of the muscle to the force developed. In both methods, the rate at which the muscle shortened was controlled. They concluded that the greater the speed of contraction, the less force the muscle exerted at any length. Gasser and Hill explained their results in these words, "the dependence of force exerted on the speed of shortening was the result merely of the viscosity of the muscle".

Levin and Wyman (61) obtained the work done by the jaw muscles of the dogfish by measuring the area under tension-length curves. The work was plotted against the speed of movement for quick release and stretch experiments. The resulting curves were not linear but S-shaped, and to Levin and Wyman, this suggested the presence in the muscle of an element of free or undamped elasticity.

Hartree and Hill (30) utilized the identical method to determine work as Levin and Wyman. Results indicated that if the shortening speed was too high or too low, little work was done. For the high speeds of contraction, Hartree and Hill believed that little work occurred because the viscosity of the muscle increased as the rate of shortening increased.

Stevens and Snodgrass (87) used the gastrocnemius muscle of the decerebrate cat to determine the speed of shortening of the muscle, the force developed, the work done and the power expended during each 0.011 second of the contraction cycle. With the method employed, both the tension and length of the muscle were allowed to vary concomitantly during the same contraction against an inertia system. It was thus possible to determine accurately the entire range of tension and corresponding length changes throughout the same contraction cycle.

The results presented were the averages of eleven records obtained from the same animal during the same experiment. The curve relating the force developed to the velocity of muscle shortening revealed that as the speed of contraction increased, once the muscle had developed maximal tension, the force diminished. They concluded that some of the loss of force was due to the viscosity of the muscle. Further, that the inverse relationship between velocity of contraction and force depended upon the fact that constant power was exerted by the muscle at this time.

Stevens and Metcalf (86) used the same apparatus and method as that used by Stevens and Snodgrass. The velocity of contraction, force, work and power were calculated for small time intervals of the contraction cycle. Results were chosen from one cat as typical of the 15 animals used in the series of experiments. All experiments were quick releases. When the force was plotted against the corresponding speeds of shortening, they concluded that over a certain portion of any given contraction the force varied in a linear manner with increasing speeds of shortening. The results were interpreted and explained by the viscous-elastic theory as proposed by Hill (36) that the decrease in force might be predicted "with certain simple assumptions as to the viscous resistance of the muscle to change of form".

Fenn and Marsh (22) used the sartorius muscle of Rana pipiens except for a few experiments on the gastrocnemius to show the relationship between the force exerted by the muscle and its velocity of contraction. The velocity of contraction was always measured near the beginning of shortening where the slope of the tracing was constant and maximal. No attempt was made to calculate the magnitude of inertia.

It was reasoned, that since there was no change in velocity, the tension in the muscle would be equal to the load. The force was calculated per cm^2 cross section of the muscle. In most experiments, the muscle was stimulated for a series of loads increasing in steps from minimum to maximum and then decreasing in the reverse order. The maximum speed of shortening was measured for the series of different loads, the measurement being made always at approximately the same muscle length. When the force or load was plotted against the velocity of shortening, the curve was not linear, but rather logarithmic in shape. They concluded that as the speed of shortening increased the force decreased not in a linear fashion as would be expected if viscosity alone was concerned, but rather in an exponential fashion. Fenn stated that "this exponential relation was concerned in some way with the processes of developing extra energy for work of shortening".

Hill (34) developed a more exact and rapid technique for muscle heat measurements so that a more consistent picture might emerge of the energy relations of muscle shortening (or lengthening) and doing positive (or negative) work. Hill showed that if a frog sartorius muscle, mounted on a thermopile, was stimulated isometrically and then suddenly released under a small load, it shortened rapidly and during the shortening the galvanometer gave a quick extra deflection. To Hill, the extra deflection implied a sudden increase in the rate of heat production of the muscle. Hill postulated that when a muscle shortened, extra heat was liberated. Experimentally, Hill found that the rate of extra energy liberation was a rather exact linear function of the load, increasing as the load diminished and being zero when the load was equal to the maximal isometric force. Hill put forth an

equation which related the rate of energy liberation to the load. The equation was:

$$(P + a)v = b(P_o - P) \quad \text{(I)}$$

where,

P = the load on the muscle;

a = a constant with the dimension of force;

v = the velocity of shortening;

b = a constant defining the absolute rate of energy liberation; and

P_o = the maximal isometric force.

This equation was also written as:

$$(P + a)\ (v + b) = (P_o + a)b = \text{constant} \quad \text{(II)}$$

which related the velocity of contraction and the force in isotonic shortening. In this equation:

P = the load on the muscles;

a = a constant with the dimension of force;

v = the velocity of contraction;

b = a constant with the dimension of velocity, and

P_o = the maximal isometric force.

In another set of experiments, Hill (34) showed that when a contracting muscle was made to lengthen gradually by applying a load rather greater than isometric tension, there appeared to be a negative heat of lengthening and the total energy given out by the muscle was less than in an isometric contraction. These experiments on heat and lengthening made it impossible any longer for Hill to regard viscosity as the primary cause of the effects observed in active muscle. He stated, "if viscosity were the chief reason for

a decrease in force as the velocity of contraction increased, then lengthening of the muscle should produce greater heat production and certainly not less than isometric tension".

In a number of other experiments, Hill (34) used a series of different loads to show the relation between the speed of shortening and load in an isotonic contraction. Hill found that the experimental points of load and velocity fit the curve described by his "characteristic equation". He concluded that an active muscle shortened more slowly under a greater force, not because of viscosity, but as Fenn (22) had claimed, "to the manner in which the energy liberation was regulated". Further, Hill deduced from the force-velocity curves, that the greatest rate of doing external work (power), should occur with a load equal to about 30% of the isometric tension.

In continuation of Hill's work, Katz (51) performed experiments to confirm the force-velocity relation utilizing Hill's characteristic equation. The experiments were made on the sartorious muscle of Rana temporaria, Rana esulenta, and on the retractor penis of the tortoise. The muscle was extended by a small initial load and allowed to shorten several millimeters against various loads. Katz tested the predicted relation of the force-velocity curve using the values of the constants a and b from Hill's equation. In most cases, the observed experimental data fitted the exponential form predicted by the equation which related the velocity of shortening and the external force.

Abbot and Wilkie (2) described experiments in order to examine the relation between force and velocity in lengths other than that which was found in the resting condition in the body. The reason was that Hill's equation could only be applied in the region of this

maximum, where the variation of maximal isometric force with the length of the muscle was slight; for the maximal isometric force appeared in the equation as a constant. All experiments were made on the sartorius muscle of Rana temporaria. Tension-length curves were measured before and after the series of isotonic shortenings. Conclusions drawn from the results, showed that Hill's equation did apply at all degrees of shortening as long as the isometric force at any length at which the velocity was measured was given the new value appropriate to that length.

MacPherson (63) compared two isometric contractions, one with and the other without a known compliance added in series, in order to calculate the force-velocity relation of the frog sartorius muscle. The sole assumption required was that the velocity of shortening at any moment was a function only of the load at that moment. The tension developed by the muscle and the rate of change of tension were recorded simultaneously throughout the growth of a maintained isometric contraction. A similar record was made with extra compliance. The results revealed that the force-velocity curve always emerged with the expected form.

Ritchie and Wilkie (80) used the sartorius muscle of the frog to determine force-velocity curves from isotonic contractions. They found that about one-third of the force-velocity curves from the experiments did not fit when Hill's equation was applied because they had a straight region at the high force - low velocity end. Ritchie and Wilkie found a somewhat better agreement between experimental results and the predicted curve by using Carlson's equation which was not tied down to any specific algebraic formula for the force-velocity

curve.

Hill (33) used the frog sartorii muscles to show the efficiency of mechanical power development and its relation to load. In most of the experiments the muscles were allowed to shorten as soon as they could lift the load. In a few, they were released later. Hill found that the optimum load for efficiency was about 45% full isometric tension. The optimum value for power development was practically constant at about 30% of maximal isometric force.

(2) Intact Human Muscle

Hill (36) devised a heavy flywheel to provide the inertia against which the arm muscles had to work. A string was attached around one of a series of pulleys and the subject pulled the end of a string which produced rotation of the flywheel. Variation of the equivalent mass of the flywheel was obtained by winding the string around one or the other of the different sized pulleys of the flywheel. The speed of rotation was measured by a hand tachometer. In all subjects tested, the results clearly indicated that the greater the equivalent mass, the greater the work done. Hill also found that the greater the duration of shortening, the greater was the work done. Hill hypothesized that a muscle, when stimulated, produced potential energy which in any actual contraction was employed partly in doing external work, and partly in overcoming the viscous resistance of the muscle to its change of form. Further, the energy dissipated in overcoming the viscous resistance to a given change was proportional to the speed with which the change was carried out and to the co-efficient of viscosity of the muscle fluids.

Lupton (62) re-investigated Hill's findings with certain modifications of the method utilized. A quick release mechanism was designed

to insure that the movement did not commence before the maximum force developed. The speed of rotation was measured by a hand tachometer. Lupton eliminated errors due to fatigue by having the starting point of the experiments the pulley with the largest equivalent mass, taking readings on each pulley until the one with the smallest equivalent mass was reached and then repeating in reverse order. Lupton's results were in agreement with those of Hill, that the external work was diminished through viscosity by an amount depending upon the velocity of shortening.

Hansen and Lindhard (28) used an apparatus similar to Hill's heavy flywheel. The work performed in a pull was determined for a series of pulls by the same subject. Two series were performed on the same day, firstly, a series beginning with the greatest pulley and ending with the smallest and later, a series in the reverse order. The duration of the pull was determined by means of a stop watch. Tension was determined by inserting a Collins dynamometer between the handle of the string and the inertia wheel. The subject placed his arm on a table and while the length of the string was successively varied, made a series of maximal pulls against the dynamometer. In this way, the angle of flexion of the elbow joint corresponding to a point where maximal tension was exerted could be constructed graphically. Results regarding the relation between work and varying the equivalent mass were quite similar to those obtained by Hill (36).

Hill, Long and Lupton (38), chose a given pulley of the inertia wheel and had the subject make a series of maximal contractions employing the quick release mechanism. On a signal, the subject made and maintained a maximal effort and after an interval measured on a

stop watch, the wheel was released. The interval was varied arbitrarily between 0 and 3 seconds. They concluded that the work decreased in a linear manner as the speed of shortening was increased.

On the assumption that the force exerted by a muscle is used mainly in overcoming the viscosity of the muscle, Furusawa, Hill and Parkinson (25) developed an equation to show that the motion of a runner, starting from rest and exerting a maximal effort, propelled the runner with a constant force which was retarded by a viscous resistance proportional to the speed.

Best and Partridge (4) used the equation of the motion of a runner, to investigate whether the maximum speed obtained by a runner depended upon the maximal force and the viscous resistance of the muscles. One subject was used to study the effects of external resistance because this subject could reproduce his maximum speed in different runs on the same day with great consistency. As a routine procedure, the subject first ran without an external resistance, then two or three runs with different external resistances and a final run without resistance. The results showed that the average difference between the observed maximum speeds and that calculated from the equation was approximately 0.015 yds. per second. Therefore, the maximum speed of the subject when external resistance was applied was decreased by an amount calculated from the equation of a runner. They concluded that the internal resistance of the muscles (viscosity) was real in a sense that it had identically the same effect as an externally added resistance.

Dickenson (17) described an investigation to determine the maximum speed of pedalling a bicycle ergometer as a function of the

load applied to the wheel. In each recording the subject began with one pedal ready to be pushed downwards at an angle of 45° from the top position. The subject pedalled as fast as possible for about ten seconds. The maximum speed was found to be attained about four seconds from the start. The results indicated that the relation between maximum speed and load was linear.

Fenn (21) illustrated a new method of demonstrating muscle viscosity in sprint running. The subject sat on a table with one leg hanging over the edge and arrangements were made for recording variations in the angle of the knee with time as the lower leg moved. A curve was traced by a pointer on a revolving drum as the lower leg moved which indicated angle of the knee plotted against time. The slope of the curve represented the angular velocity. If the angular velocity measurements were plotted as a function of time, the slope of the resulting graph presented the angular acceleration. The results indicated how quickly the force decreased following a quick release of the lower leg. Fenn suggested that the failure to develop force while shortening may be due partly to a reflex cessation of stimulation or a reflex inhibition. He also suggested that the loss of force may be due to some characteristic of the muscle itself. He stated that "the delay in development of tension might equally well be in some chemical reaction involving the mobilization of the necessary energy for contraction. In such a case, the term viscosity would be inappropriate".

Fenn, Brody and Petrilli (23) made arrangements to obtain a kymographic record of the position of a moving arm or leg as a function of time. The slope of this graph gave the angular velocity at every moment during the movement. If these velocities were plotted, a smooth

graph drawn through the points, the slope of this curve gave the angular acceleration of the movement. Knowing the moment of inertia of the limb, the force exerted at various moments were calculated. The force exerted by the subject was determined at the moment when the limb was held isometrically and then suddenly released by pulling a pin. From the resulting acceleration of the limb as deduced from the graphical record of the swing, the moment of inertia of the limb was calculated and was found to agree within 10% with the value estimated from the weight of the individual and the dimensions of the limb. When the force exerted in the quick release experiment was plotted against the velocity at different moments during the swing, it was found that the tension decreased as the speed of movement increased.

Dern, Levene, and Blair (16) studied the relationship of force to velocity in maximal flexions of the human forearm. The apparatus was designed to supply constant force with as little inertia in the system as possible. The force could be used directly or converted to a constant torque to oppose the movement of the arm. In order to produce a series of moments of inertia about the elbow joint, flat lead weights of 1 kg mass were added to the end of a lever. The movement in all experiments was recorded when a thread from the periphery of a small pulley was attached to a lever which wrote on a kymograph. Therefore, the instantaneous velocities for a series of points along the contraction could be determined. The subject made a maximum voluntary flexion against opposing loads applied in three ways: (1) the reaction of various moments of inertia; (2) constant torques about the elbow joint; and (3) isotonic forces applied parallel to the forearm flexor muscles. The results revealed that the force-velocity

curves obtained at 80% of flexion for contraction against inertias and constant torques were similar for a given subject but were different from the curves with techniques using increasing torques. The experimentors concluded that force-velocity curves were different when different techniques of applying the opposing loads were used. Further, since electromyography records indicated activity of antagonist muscles in all contractions, they believed that the true force-velocity curve of human muscle must lie outside their experimental curves; the true isometric force would be greater than that measured at 80° flexion and the maximum velocity in the order of 160% of the measured maximum. They stated that "the exact course of the curve is not determinable from simple force-velocity measurements in the intact arm". Although the data could be rather accurately represented by a rectangular hyperbola, they concluded that there was no evidence that the characteristic equation developed by Hill (34) would apply to human isolated muscle.

Ralston, Polissar, Inman, Close and Feinstein (79) studied voluntary contractions of the human pectoralis major, bicepts brachii and triceps muscle under isometric and isotonic conditions in subjects having cineplastic muscle tunnels. The isometric contractions were measured with a strain gauge dynamometer. For the measurements of rates of shortening of the muscle under various loads, a light lever constituting one arm of a resistance bridge was connected to a cable supporting the load. As the load was lifted, the bridge unbalance was measured by a Heiland type A galvanometer and recorded on a Heiland type SE-301 R-12 oscillograph. Concerning the relation between load and maximal velocity, every attempt was made to reproduce as closely as possible the experiments made on frog muscle by Fenn and

Marsh (22) and Hill (34). The muscle was initially stretched with a load of 0.32 kg to a length slightly beyond resting length, all greater loads being supported by a block. The subject was instructed to shorten his muscle as rapidly as possible upon receiving a signal. At least two sets of measurements, in ascending and descending series, were made in each experiment. The maximal force developed at the initial length was determined with the isometric dynamometer. The results indicated that the curve relating load and maximal velocity could be fitted by the characteristic equation as found by Hill (34) using frog muscle. They concluded that an isolated human muscle would develop maximal power when lifting a load equal to about one quarter to two fifths of the maximal isometric tension the muscle can develop.

Wilkie (90) used a triangular oak lever axle which ran freely in self-centering ball bearings to determine the relation between force and velocity in human arm movement. The subjects pulled on a lever through a Bowden wire cable in which the tension was varied by altering a suspended weight. The subject kept his upper arm fixed during each movement by pressing it against a padded block of wood fastened to the table. Movement of his body was prevented by a vertical board at the end of the table. In order that the force applied by the arm be constant throughout each movement, the cable remained horizontal. The velocity of each movement was estimated from a charge which accumulated on a condenser. The velocity of the subject's hand was always measured at the end of the movement, when the arm was at an angle of 80° with the horizontal. The load was supported by a stop so that the lever was at 140 degrees with the horizontal before each movement. At the end of the movement (75°) the load was held by a spring catch. The isometric

tension was measured by a simple spring balance, with the forearm at an angle of 80 degrees with the horizontal, that is, in the same position at which velocity was measured. For one subject, the tension at the hand was varied in eleven steps from 0-15.23 kilograms and at each step 30 measurements of velocity were made. Only five velocity measurements at the same tension were made at one time and each one followed a rest period of at least one minute to avoid fatigue. When the experimental relationship of mean velocity was plotted against the force it remained to be seen whether the experimental exponential curve would be described by Hill's characteristic equation. After the few trials, it became clear to Wilkie that the experimental results did not fit the equation except at tensions greater than 30% P_o. It seemed to Wilkie that the inertia of the apparatus and fore-arm might so diminish acceleration that the full velocity could not be reached before the movement was completed. After correction for the inertia of the forearm and the apparatus, the force-velocity curve could be represented by Hill's equation. Experiments were done on another 4 subjects and each experimental point of the force-velocity curve was based on 5 instead of 30 determinations of velocity. The fit with the characteristic Hill equation was in every case quite good. Although the maximal force varied in subjects from 12 to 20.5 kilograms, the maximal velocity of movement (V_{max}) attained was relatively constant at (670-775 cm/sec).

Komi (59) presented a report which dealt with a dynamometer designed for the measurement of the force-velocity relationship of the human forearm flexors and extensors. The dynamometer was capable of recording both the isotonic force (either eccentric or concentric) and

changes in muscle length (elbow angle) with 8 different velocities of shortening and lengthening of the elbow flexors and extensors. Thus, to obtain the force-velocity relationship, a total of 16 different constant speeds could be selected along with the velocity axis. The dynamometer was so constructed that the velocity of lengthening and shortening of the biceps brachii muscle remained as constant as possible throughout the movement range of approximately 120^{o}. This corresponded to a 7 cm. change in length of the biceps muscle of an adult man. The speed range varied from 0.8 to 6.7 cm per second when measured from the biceps muscle. The velocity of contraction was obtained with a photo-electric transducer which gave an impulse on a oscillography at each spindle revolution. Strain gauges to record the force were installed on both sides of a special wrist cuff, which allowed the wrist to be fixed at any desired position between full supination and full pronation. The force-velocity curves that were obtained for the elbow flexor muscles followed closely the classical force-velocity form obtained with isolated muscle.

Kawahatsu (55) constructed an isotonic lever-pulley apparatus equiped with variable weights in order to measure the force-velocity relation and the mechanical power of the human leg extensor muscles. The velocity of knee extension was calculated from the angular velocity which was recorded by an electrogoniometer connected to the shaft of the pulley. The exerted force was measured by a strainguage tensiometer. Kawahatsu observed that the relative position of the force-velocity relation was specific to different athletic events. The force-velocity curve emerged the highest for sprinters with middle distance runners next and long distance runners the lowest .

Kawahatsu (56) used the same apparatus to measure the force-velocity relation of the leg extensor muscles of a child, adults and athletes. When comparing the adult male with the male child, Kawahatsu found that the maximum velocity of movement (V_{max}) of the child (5 yrs) was 75.5% of the adult and the difference became greater as the exerted force increased. Although, the high jumper and sprinter had equal peak maximal mechanical power output, the jumper produced his peak power by a higher ratio of force against his maximum isometric force than did the sprinter. However, the sprinter produced an equal peak power by providing a higher ratio of velocity against the maximum velocity (V_{max}).

Kawahatsu (53) investigated the force-velocity-power relationship in 277 males whose ages ranged from 15 to 72 years. The measurements were made on the extensor muscles of the right leg. He found that the maximal values of force, velocity and power were significantly different between different age groups. In addition, that the maximal isometric force (P_o) decreased considerably after the age of 20 years while the maximal unloaded velocity (V_{max}) as well as the maximum exerted force decreased after 15 years of age.

Thorstensson, Grimby and Karlsson (89) made measurements of the force-velocity relationship of the knee extensor muscles in 25 male subjects (17 - 37 yrs.) by means of isokinetic contractions. Muscle biopsy specimens were obtained from the medial vastus lateralis and classified as fast twitch (FT) and slow twitch fibers on the basis of myofibrillar ATPase activity. The fiber area was measured on the basis of NADH diaphorase staining. The investigators found a significant correlation between relative area of FT fibers and the peak torque

produced at the highest measured velocity of 180^{o}/sec. In addition, the maximal unloaded velocity of contraction (V_{max}) was found to be significantly correlated to percentage of FT fibers as well as area.

Ikai (43) was the first to approach the problem of training of muscular power by considering the force-velocity relationship of muscle. He measured individual force-velocity curves of the forearm flexor muscles for thirteen male and fifteen female adults. The maximum power produced was found when the force and velocity were about 35% of the maximum values in both sexes. A power training study was conducted in twelve male adults to see the effect on the force-velocity relationship of the forearm flexor muscles. The load used for isotonic training was zero, thirty, sixty, or one hundred percent of the maximum isometric strength (P_o). The training consisted of ten maximal voluntary contractions of the elbow flexors once a day lifting the load specific to the group. The results indicated that a greater displacement of the force-velocity curve, and consequently better all-round improvement in maximal muscular power, was obtained with the subjects that used the thirty and sixty percent training loads. He concluded that for all-round power training, that a load from thirty to sixty percent of the maximum strength should be used.

Kawahatsu (52) used continuous training for ten months on the bicycle ergometer and found that the greatest displacement of the force-velocity relationship occurred at peak maximal mechanical power output. He concluded that the increase in MMPO was due to an increase in the maximal exerted force at peak MMPO with little increase in the maximal velocity of contraction. There was no significant increase in maximal isometric force (P_o).

Moffroid (70) used isokinetic exercise to evaluate the effects of

two different training speeds (36 and 108 degrees per sec) on muscular endurance (average power) and on muscular force. Peak torque at different velocities of contraction (18,36,54,72,90,108 degrees per second) was measured for the quadriceps and for the hamstring muscle group. She found that the slow training speed of 36^{o}/sec produced increases in muscular force only at slow speeds. On the other hand, the faster speed of 108^{o}/sec produced increases in muscular force at all speeds of contraction at and below the training speed of 108°/s.

Summary

Because the review of the literature on the force-velocity relationship of contracting muscle is quite extensive, a brief summary is presented in order that a general picture may be obtained of its development and importance to the present study.

The discovery of the force-velocity relation really began with preliminary studies that were concerned exclusively with the relation between the speed of muscular contraction and the external work. It was shown that for isolated striated muscle (26,30,61) as well as intact human muscle (28,36,38,62) that the work decreased as the speed of shortening increased. Hill (36) fostered the belief in his early work on human arm movements, that the potential energy for contraction was used partly to overcome the viscous resistance of the muscle to its change of form and that the energy used was proportional to the speed of shortening. Many of the early studies which related speed of shortening to work (26,28,30,36,38,61,62) and some which related speed to the force exerted (4,84,87) postulated that viscosity was responsible for the inverse relationship which was found. A disagreement arose in these early studies as to whether the relationship between speed and force was linear or not. Some studies (17,36,38,62) con-

cluded a linear relationship, while other (26,30,61) did not.

The dilemma continued until work by Fenn (21) on intact human muscle suggested that the loss of force may be due to a characteristic of the muscle itself rather than viscosity. Subsequent work by Fenn and Marsh (22) concluded that the relationship between force and velocity was not linear as would be expected if viscosity alone was responsible. This was re-affirmed by Hill (34) with his experiments on heat and lengthening. In the same experiments, Hill proposed his force-velocity equation which related the velocity of contraction and the force in an isotonic shortening. Investigations have confirmed, that experimental data can be fitted to the curve predicted from Hill's equation for isolated striated muscle (2,51) as well as intact human muscle (79,90).

For isolated striated muscle, the force-velocity relationship holds true for muscle lengths other than that found in the resting condition of the body (2), can be measured by comparing two isometric contractions (63) and can be predicted using other equations (80). For intact human muscle, the force-velocity relationship can emerge differently for different techniques of applying the load (16) can be measured for flexor or extensor muscles (59) and can be displaced by isotonic (43,52), as well as isokinetic (70) training. For both types of muscle (33,43), maximal mechanical power output is developed when the load on the muscle and its velocity of contraction are approximately one-third of their maximum values.

Based upon the work of Ikai (43), it seems logical to select 30 and 60% of an individual's maximal isometric force (P_o) as the two different force-velocity training interactions and to hypothesize that both stimuli will displace the force-velocity curve "all round". However, the

utilization of an isokinetic training device allows the training stimulus to be precisely set and controlled in a manner not so apparent as with isotonic methods. Studies comparing the two methods (71,78,81,88) show definite superiority of the isokinetic method and this may lead to a different alteration of the force-velocity relationship and peak power.

The review of the literature has also revealed that although individuals may be relatively similar at the extreme ends of the curve, the curvature may vary in a manner that directly affects the generation of peak power. For the untrained healthy individual, the force-velocity curvature is highly correlated with the fiber composition of the muscle (89). In addition, investigators have shown (45) that untrained males and females differ only in the muscular mass and not in the strength exerted per cross-sectional area. Indeed, both sexes exert peak power at approximately 35% of their maximum force and velocity values on the force-velocity curve. Since the trainability of velocity of movement is still open to question (15,83) perhaps the key factor in the interindividual variation in peak power lies in the force exerted. The work of Kawahatsu (54) has strengthened this hypothesis and leads to the speculation that untrained individuals with different initial levels of maximal force exerted at peak power may have to be trained differently in order to place emphasis upon the force or velocity factor. The hypothesis may be made that, untrained high and low force generators may respond differentially to the 30 and 60% force-velocity training interactions.

Very few movements lend themselves to quantitative study of force-velocity data and must satisfy certain criteria (90).

1) The joint should be geometrically simple;

2) The movement should involve few muscles, which should have small

origins and insertions;

3) The movement should not disturb rigid fixation of the rest of the body, and should lend itself to graphic registration;

4) The movement should be accurately reproducible. This is easiest to achieve if only slight skill is involved.

All these criteria are substantially satisfied by the movement of flexion of the elbow. It is not surprising that much of the force-velocity data has been obtained on the intact human arm (16,28,36,38,43,59,62,70,90).

CHAPTER III

METHODS AND PROCEDURES

Subjects

Sixty female volunteers were used as subjects in a pre-training test and a post training test with a five week training program between. The subjects ranged in age from 18 to 29 years.

Anthropometrical Data

The following anthropometrical data was collected from each subject: age (years); weight (lbs); and length of forearm (cm) (middle of the olecranon of ulna to middle of palm of hand).

The Cybex II System

The recent developments of isokinetic rehabilitative apparatus have provided new tools that allow the study of the mechanical properties of intact human muscles under conditions of constant velocity. The concept of isokinetic exercise has been discussed by several researchers (8,11,40,71,85,88). The Cybex II Isokinetic system consists of three components:

(1) A Cybex II Dynamometer which measures torque inputs up to 360 foot-pounds. The resistance supplied via the input attachment varies automatically to accommodate the fluctuating force applied by the subject. Any force against the input shaft is measured as torque on the input shaft and displayed on a front gauge dial. Because of the accommodating resistance mechanism in the apparatus, the velocity of an exercising limb cannot be accelerated. Instead, as more force is exerted against the lever arm of the apparatus, more resistance is encountered by the limb and movement occurs only at a preset velocity of con-

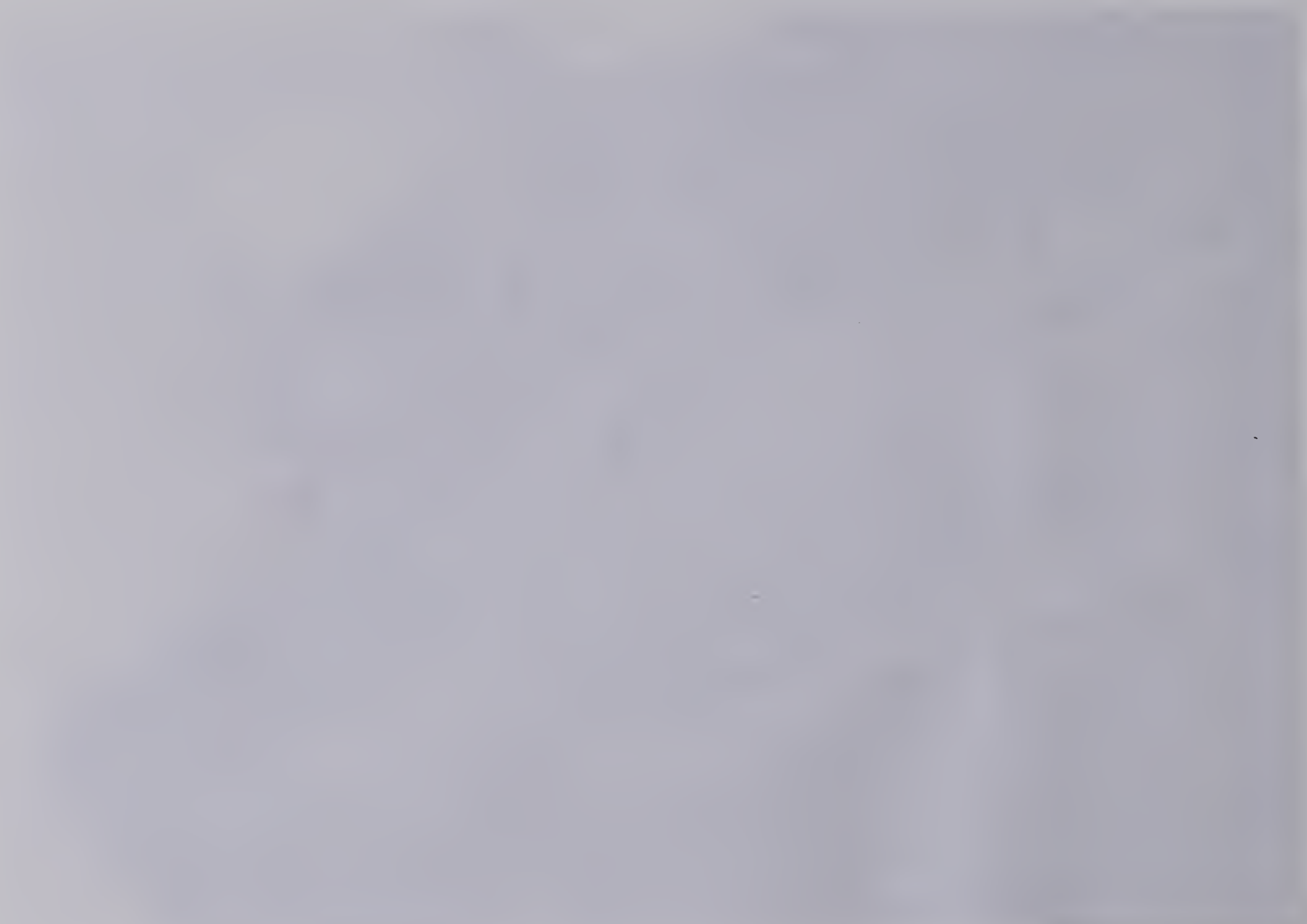
traction;

(2) A speed selector which can be preset to obtain a constant speed of rotation of the lever arm from 0 to 300 degrees/second. Once a speed is selected, the lever arm cannot be accelerated beyond that speed regardless of the input torque applied below 360 foot-pounds; and

(3) A fast response recorder and heated stylus which simultaneously produces and displays a permanent written record of the applied torque.

The Cybex II Isokinetic System is shown in Figure 1. For calibration of this system see Appendix S.

Figure 1: The Cybex II Isokinetic System



Initial Familiarization

Sixty-two subjects came to the rehabilitation medicine laboratory one week prior to the pre-training test in order to familiarize themselves with the movement of the lever arm of the isokinetic dynamometer. Each subject was placed in the resting supine position on a table with both forearms supinated. The Cybex II Dynamometer was adjusted such that the axis of rotation of the Cybex was in line with the right elbow joint and the handle of the lever arm rested comfortably in the middle of the palm of the hand. A number of different pre-set speeds were selected from 30 to 300°/s and from an experimental starting position of 180° (horizontal) the subject was given the instruction to move the lever arm as fast and as hard as possible throughout the entire range of flexion. In addition, the subject was told not to lift the elbow from the table during the movement. In some cases, adjustments were made when it became clear that the length of the lever arm was incorrect and did not allow optimal movement. This procedure was repeated for the left arm. The period of familiarization of dynamic contractions lasted approximately 10 minutes per subject and afterward, the anthropometric measurements and the optimal lever arm length were recorded. Through a series of questions which related to the use of the forearm it was determined that only 2 subjects were left arm dominant and the results excluded and destroyed. The 60 remaining subjects were then scheduled for the pre-training test.

Pre-Training Test

The pre-training test was performed over a period of 11 days. Each test session was approximately one hour in length per subject. The subject was placed in the identical experimental starting position as

for the initial familiarization session. The pre-test involved measurements of the maximal isokinetic torque (ft lbs) produced by the contracting right forearm flexor muscles at an elbow angle of 90 degree for five preset velocities of movement of the forearm. Two trials were given at each of the pre-test velocities of 90, 150, 210, 270 and 300°/sec and the average torque calculated for the two trials. Duplicate determinations were then made of the maximal isometric torque (ft lbs) of the right forearm flexor muscles at an elbow angle corresponding to 100, 120, 140, and 160 degrees (180 degrees being horizontal). The average of the two trials was recorded as well as the highest average which was used as the maximal isometric force (P_o) for the subject. Each subject was given a one minute rest period between each trial.

Determination of the Maximal Exerted Force at Peak MMPO

In order to separate individuals based upon their ability to exert maximal force at peak MMPO, the following procedure was followed. From the pre-training test data, the maximal average torque (ft lbs) and its corresponding maximal velocity of movement (degs / sec) were converted to their equivalents of force (kg) and velocity (m /sec) for each individual (see Appendix A and B for conversion). These five experimentally obtained force-velocity points as well as the greatest average maximal isometric force (P_o) were plotted for each individual by the IBM 360 computer at the University of Alberta (figure 2).

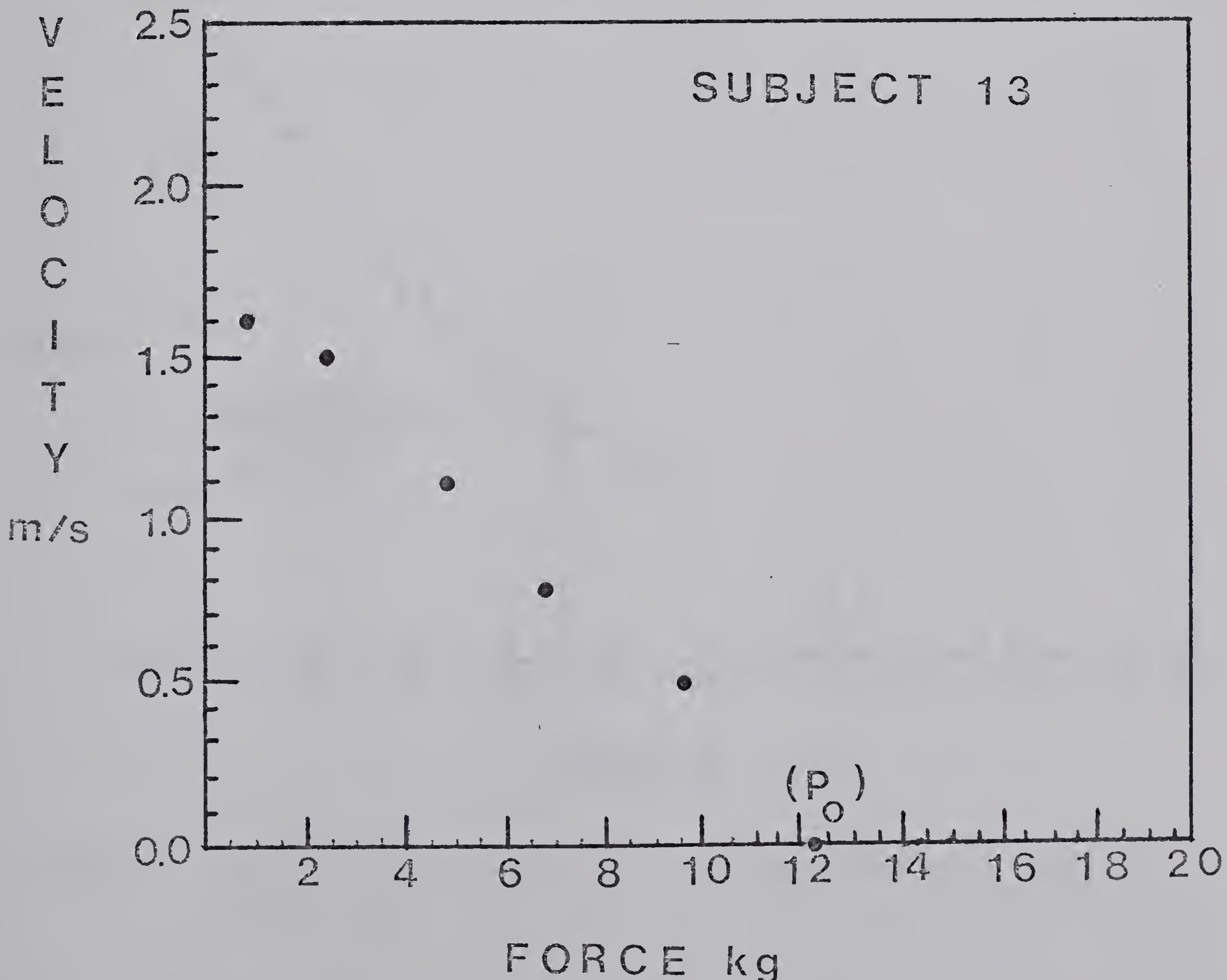


Figure 2. Plot of maximal force and velocity for subject #13

The computer was pre-programed (see Appendix C) to calculate and plot 18 "best-fit" exponential points based upon the five experimentally obtained force-velocity values in figure 2. This allowed the prediction of predicted maximal velocities from predictor forces no more than 1 kg apart. A "best fit" force-velocity curve was then drawn (fig 3).

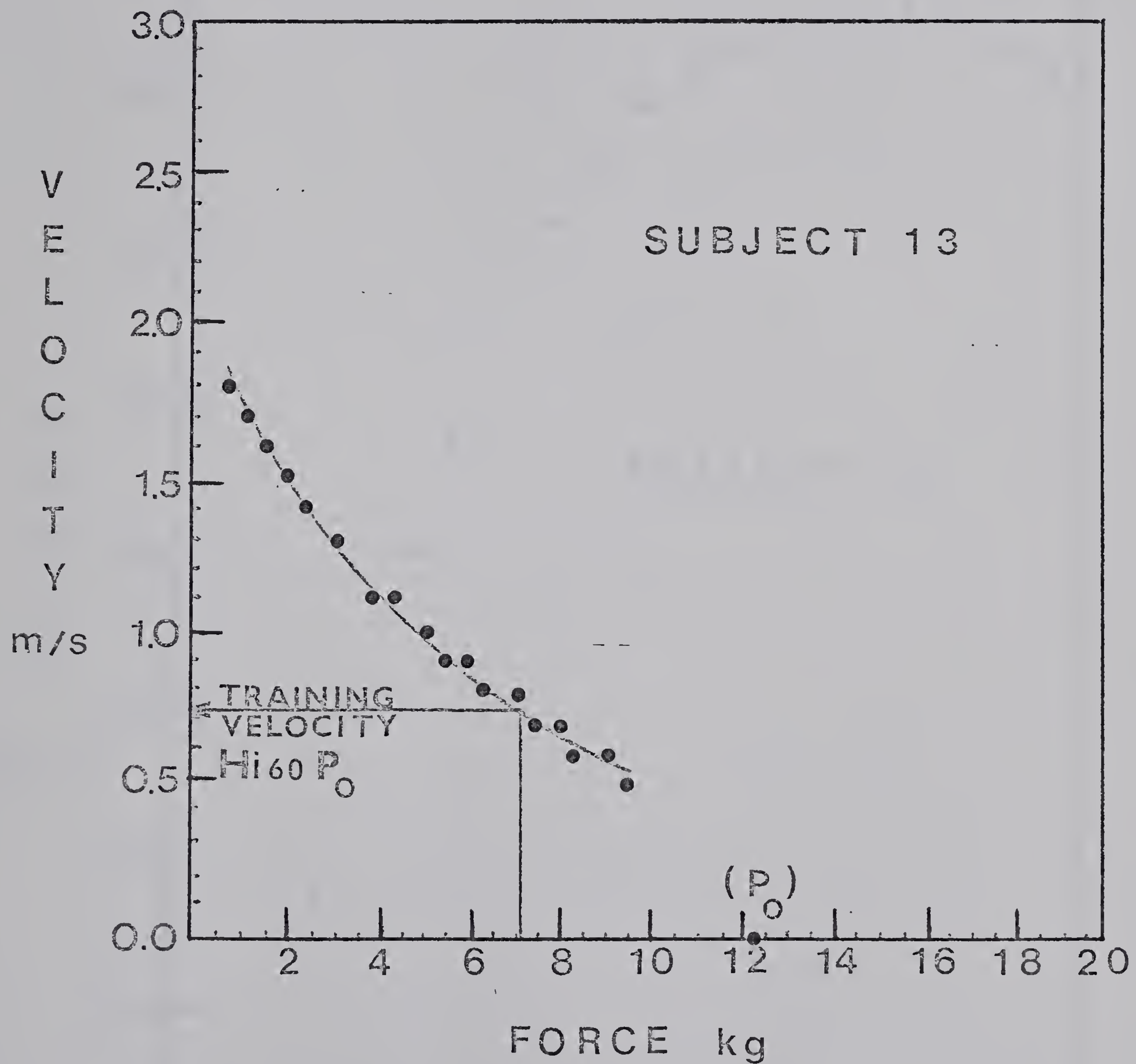


Figure 3. Plot of 18 "best fit" points and force-velocity curve for subject #13

In addition, MMPO (kgm /sec) was calculated and plotted as the product of force (kg) multiplied by the maximal velocity of movement (m /sec) for the 18 "best-fit" force-velocity points (figure 4).

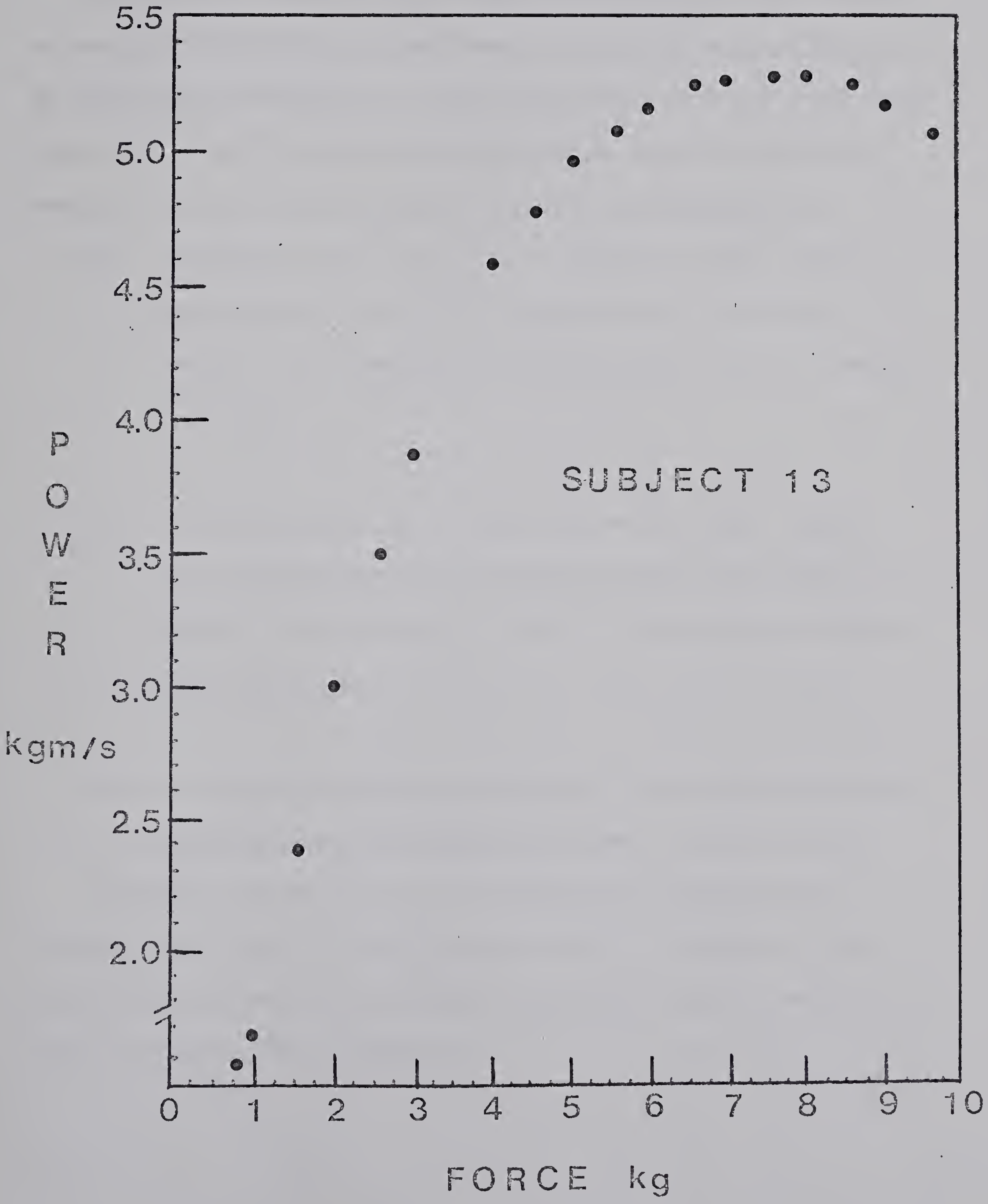


Figure 4. Plot of MMPO from "best fit" force-velocity curve for subject #13

A computer print-out of the 18 force-velocity points and corresponding MMPO revealed the maximal force exerted at peak MMPO for each individual.

Assignment of Subjects to the Training Groups

From the pre-training test scores of the maximal force exerted at peak MMPO, the subjects were ranked and classified into blocks of 30 individuals designated as a high force group (Hi) and a low force group (Lo). The 30 subjects from each block were then randomly assigned to one of three groups as follows: (see Appendix E)

(I) a training group (30 P_o) who trained the right forearm at a maximal velocity of movement which corresponded to a maximal force production of 30% of their maximal isometric force (P_o);

(II) a training group (60 P_o) who trained the right forearm at a maximal velocity of movement which corresponded to a maximal force production of 60% of their maximal isometric force (P_o); and

(III) a control group (C) who was asked to maintain their same activity pattern during the five week training period.

Therefore, there were four training groups designated as (Hi $30P_o$), (Hi $60P_o$), (Lo $30P_o$) and (Lo $60P_o$). In addition, the control groups from each block were designated as (Hi C) and (Lo C). All groups contained 10 subjects.

Determination of the Individual Maximal Training Velocities

Maximal training velocities corresponding to a maximal force production of 30 or 60% of an individual's maximal isometric force was determined from individual pre-training force-velocity curves as shown in figure 3. A perpendicular line was drawn from the force axis to a point on the "best-fit" force-velocity curve and then extended at a right angle to a point on the velocity axis. The maximal training velocity (m /sec) was then converted back to an angular training velocity (degs /sec) for the Cybex II utilizing equation IV (Appendix A).

Post-Training Test

The post-training test involved exactly the same measurements as were made during the pre-training test. The training groups (Hi $30P_o$), (Hi $60P_o$), (Lo $30P_o$) and (Lo $60P_o$) were tested over a period of 3 days (Sat., Sun. and Mon.) following the 5th week of training. The control groups (Hi C) and (Lo C) were re-tested during the 6th week (Tues. to Sun.).

Determination of Composite Force-Velocity-Power (F-V-P) curves

Composite F-V-P curves were obtained by utilizing mean values obtained from the individual force-velocity data.

Experimental Design and Statistical Procedures

The experimental design utilized was a 2 x 3 x 2 factorial design (fixed model) with repeated measures on the last factor.

The two levels of the first factor (factor A) (classification) were the two blocks of 30 individuals into which the subjects were assigned based upon their ability to exert Hi or Lo maximal force at peak MMPO. These two levels were:

(a_1) a group that exerted Hi force production at peak MMPO; and

(a_2) a group that exerted Lo force production at peak MMPO.

The three levels of the second factor (factor B) (treatments) to which the two levels of factor A were randomly assigned were:

(b_1) a maximal training velocity which corresponded to a maximal force production of 30% of an individuals maximal isometric force (P_o);

(b_2) a maximal training velocity which corresponded to a maximal force production of 60% of an individuals maximal isometric force (P_o); and

(b_3) a control group that did not train.

The two levels of the last factor (factor C) (repeated measure) were:

(c_1) the pre-training test scores; and

(c_2) the post-training test scores.

Statistical Procedures

The data on each parameter was analysed by a three-way analysis of variance with repeated measures on the last factor. More specifically, the analysis was carried out on the dependent variables of:

(I) the maximal force (kg) exerted at the five different pre-set velocities of movement;

(II) the maximal isometric force (P_o); and

(III) the peak MMPO.

The changes in these variables were used as an index of the alteration of the F-V-P relationship by isokinetic training. In addition, the analysis was performed on the maximal force and velocity exerted at peak MMPO in order to evaluate the effects of the isokinetic training in individuals who possess different initial levels of maximal force at peak MMPO.

Where significant ($p < .05$) F ratios were obtained for the interactive effects, a Neuman-Keuls procedure as designed by Harter (29) was used to compare the means of the individual group interactions from pre to post-test. The mean square within cell error obtained from the previously done three-way anova was used to calculate the standard error.

In addition, one way anovas were applied to the means of the significant interactions at pre as well as post-test. The numerator of the F ratio was the mean square obtained from a normal one-way anova but a pooled error term obtained from the previously done three-way anova provided the denominator. Where significance ($p < .05$) occurred, a Neuman-Keuls test of ordered means (24, p. 272) was applied. Again, the pooled error term was employed in the calculation of the standard error. All computations were done on the IBM 360 computer and the Olivetti Programma 101 at the University of Alberta.

The Training Program

The training groups trained three times a week for a period of five weeks. The training program is shown in Appendix D.

CHAPTER IV

RESULTS

Attrition in the training groups was relatively high and by the end of the 5 week training program the training groups contained only 7 subjects per group that had completed all training sessions. It was decided to randomly exclude 3 control subjects from the Hi and Lo control groups in order that equal numbers be present for the statistical analysis.

Anthropometric Data

Measurements obtained from the 60 female volunteers during the initial familiarization period are shown in Appendix F-I. Subjects numbered 1 to 42 are the remaining experimental subjects. Subjects 43 to 60 did not complete the post-training test.

Raw Scores

A retraced example of the tracing obtained from the Cybex II for subject #31 at pre-test is shown in Appendix H-II. All measurements of dynamic torque were made at the beginning of inflection of the spike which indicated by a micro-switch that the elbow angle was 90 degrees. It has been mentioned recently (76) that at higher velocities, the subject's limb may pass through several degrees of a desired arc of movement before the limb reaches the prescribed velocity. In other words, the human limb cannot accelerate fast enough to catch the constant pre-set speed of the isokinetic dynamometer. That this is true can be seen by examining the raw scores at the higher velocities where a few subjects

produced zero torque. It must be mentioned, that maximal torque is only registered as a tracing when the prescribed speed is met. This "slack" (76) may be a drawback to precise measurements of maximal torque at higher velocities when the Cybex dynamometer is utilized. Indeed, inspection of the tracings (Appendix H-II) shows that for 210, 270 and 300°/s, a slightly higher maximal isokinetic torque is registered after 90 degrees and this observation seemed fairly consistent for most subjects. It is very probable that the acceleration phase of the Cybex is the major contributor to this phenomena. The assumption made (p. 5) that time and velocity of movement are independent variables may only be tenable at velocities of 150 degrees/second or lower.

For subjects 1-42, conversion of the five pre-set maximal angular velocities (degrees per second) to their linear equivalents (meters per second) is shown in Appendix H-I. The raw scores obtained for each individual during the pre and post-test sessions are shown in Appendix G-I for the 42 experimental subjects. Appendix G-VII contains only the pre-test data of the subjects that did not complete the study. Maximal isometric force (P_o) exerted at 120, 140 and 160 is not included for these individuals as these results were unfortunately destroyed. However, pre-test measurements of the five dynamic measurements of torque, maximal mechanical power output, maximal force and velocity at peak MMPO as well as maximal isometric force (P_o) are listed in Appendix G-VII. In addition, pre-test results of the six control subjects that were excluded were destroyed before it was decided to include the pre-test results of all 60 subjects. This is strictly an oversight committed by the experimentor.

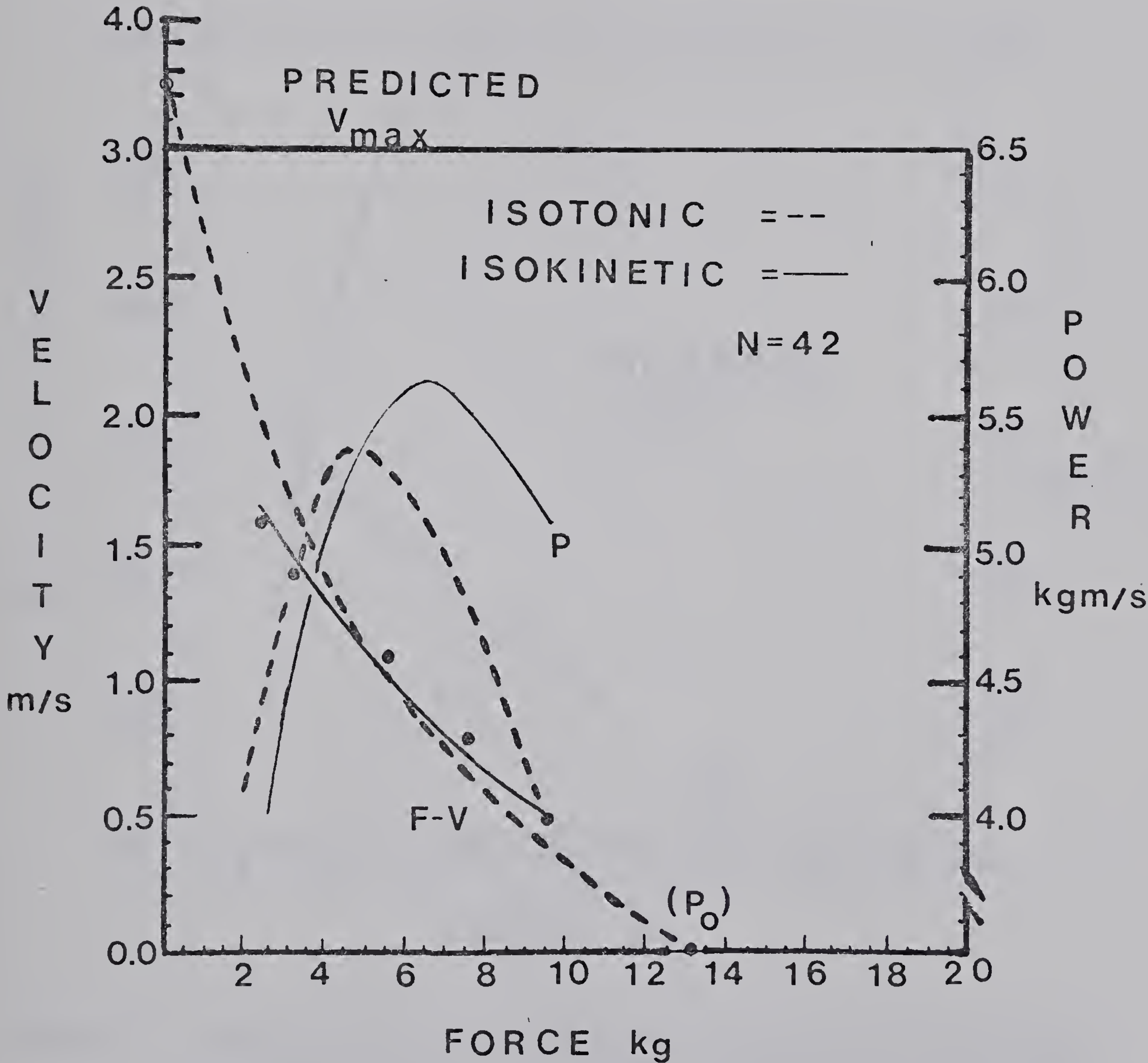


Figure 5. Composite pre-test force-velocity-power relationships for all subjects from isokinetic measurement. Isotonic curve from Hill's equation of $(P+a)(v+b) = (P_o-P)b$ where, $a = 3.3$ and $b = .8$. Ratio of $a/P_o = .25$ fully describes curve

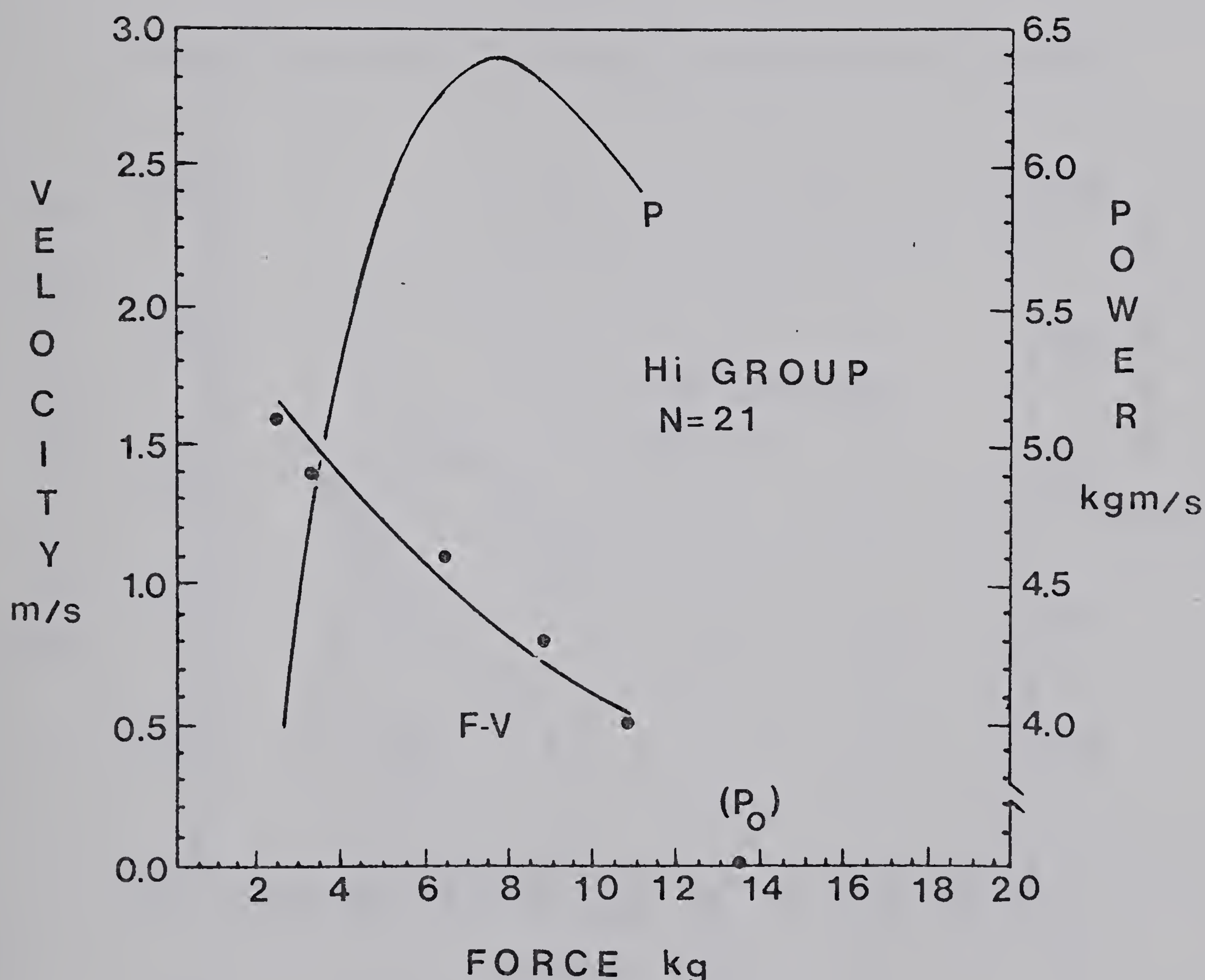


Figure 6. Composite pre-test force-velocity-power relationship for the Hi force group as derived by isokinetic measurement. Experimental points obtained from mean force-velocity values.

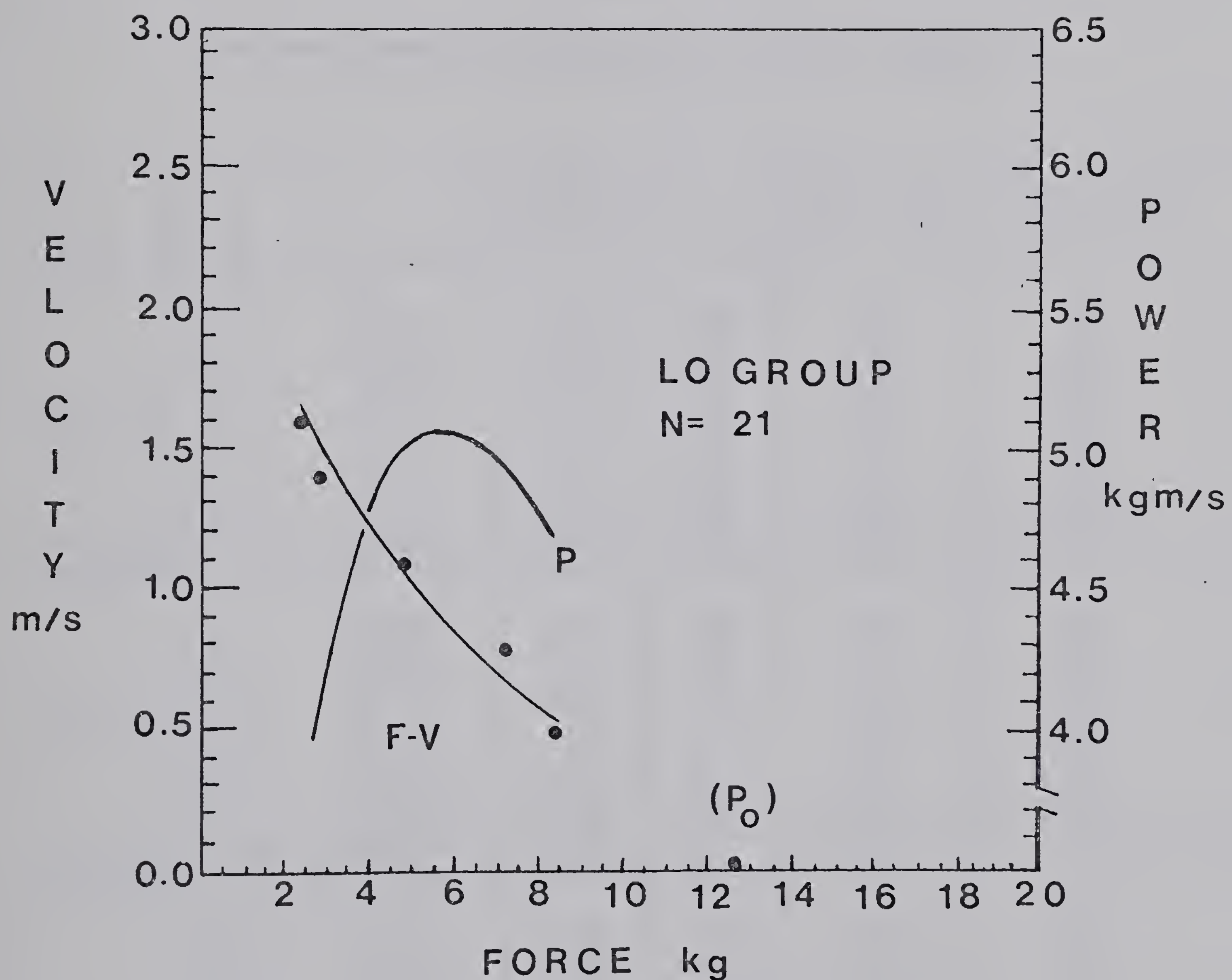


Figure 7. Composite pre-test force-velocity-power relationship for the Lo force group as derived by isokinetic measurement. Experimental points obtained from mean force-velocity values.

Individual Maximal Training Velocities

The Hi and Lo force group (N=21/group) were randomly assigned to their respective treatments of 30 P_o, 60 P_o and C. Maximal training velocities calculated for each individual specific to their assigned treatment are presented in Table I.

TABLE I

Individual Maximal Training Velocities Corresponding to a Maximal Force Production of 30 or 60% P_o

Group	Sub	Max P_o (kg)	Training Vel. (m/sec)	(°/sec)	Training Force (kg)	Angle of Max. P_o (Degrees)
Hi 30 P_o	1	10.97	1.50	296	3.29	100
	2	15.41	1.09	204	4.62	120
	3	11.80	1.00	184	3.54	100
	4	11.47	1.41	264	3.44	100
	5	11.56	1.11	231	3.47	100
	6	13.83	1.50	296	4.15	120
	7	12.92	1.50	296	3.88	120
MEAN		12.57	1.30	253	3.88	
Hi 60 P_o	8	15.55	.80	143	9.33	100
	9	11.64	.66	126	6.98	120
	10	13.32	.88	183	7.99	100
	11	12.47	.73	137	7.48	100
	12	13.16	.84	155	7.90	100
	13	12.04	.74	137	7.22	100
	14	18.51	.90	166	11.12	140
MEAN		13.81	.79	150	8.29	
Lo 30 P_o	22	12.57	1.24	215	3.77	100
	23	10.35	1.22	218	3.12	100
	24	16.80	1.40	251	5.04	100
	25	10.62	1.54	300	3.19	100
	26	13.39	1.24	222	4.02	120
	27	11.95	.71	145	3.59	120
	28	10.02	1.16	221	3.01	100
MEAN		12.24	1.22	225	3.68	
Lo 60 P_o	29	15.67	.50	95	9.40	100
	30	14.94	.61	113	8.96	100
	31	13.38	.60	111	8.03	120
	32	11.75	.86	154	7.05	100
	33	12.23	.55	107	7.34	100
	34	13.02	.43	82	7.81	120
	35	14.55	.56	113	8.73	100
MEAN		13.65	.59	111	8.19	

Maximal Force Exerted at Five Pre-Set Velocities

Pre and post-test mean forces ($\pm$SD) exerted by the treatment groups (N=7/group) for the five different pre-set velocities of movement are shown in Table II. Graphical illustrations are presented in Figures 8 and 9.

TABLE II

PRE AND POST-TEST MAXIMAL FORCE EXERTED BY THE Hi AND Lo FORCE GROUPS (N=7/GROUP) AT FIVE PRE-SET VELOCITIES OF MOVEMENT

GROUP	FORCE (kg) AT 90°/s PRE	POST	AT 150°/s PRE	POST	AT 210°/s PRE	POST	AT 270°/s PRE	POST	AT 300°/s PRE	POST
Hi 30 P_o	10.69	10.79	8.44	8.95	5.46	7.03	2.79	5.35	2.12	4.53
SD $\pm$	1.28	1.08	1.81	1.44	1.64	1.45	1.40	1.25	0.91	1.13
% DIFF	.94		6.04		28.75		91.76		113.68	
Hi 60 P_o	10.96	11.78	9.23	10.14	6.67	8.12	3.95	5.77	2.77	4.61
SD $\pm$	1.45	2.12	2.19	1.96	2.04	1.16	2.36	1.68	2.49	1.77
% DIFF	10.20		9.86		21.74		46.08		66.43	
Hi C	10.63	10.74	9.06	8.79	6.47	6.43	3.44	3.34	2.63	2.60
SD $\pm$	1.16	1.42	2.03	1.55	2.29	2.15	2.13	1.77	2.14	1.95
% DIFF	1.03		3.07		.62		2.99		1.15	
Lo 30 P_o	8.09	9.16	6.26	7.27	4.37	5.71	2.36	4.20	1.85	3.58
SD $\pm$	1.71	0.96	1.83	1.01	1.74	0.91	1.03	0.81	1.13	0.84
% DIFF	13.23		16.13		30.66		77.97		93.51	
Lo 60 P_o	8.57	11.12	6.38	9.37	4.80	7.05	2.93	5.16	2.53	4.43
SD $\pm$	1.55	2.30	2.20	2.27	2.40	2.15	1.69	1.79	0.73	1.65
% DIFF	29.75		46.87		46.88		76.12		75.10	
Lo C	8.26	8.36	6.36	6.27	4.75	4.88	2.98	3.06	2.23	2.41
SD $\pm$	2.06	1.88	2.61	2.46	1.98	1.87	1.48	1.37	1.26	1.26
% DIFF	1.21		1.44		2.74		2.68		8.07	

Summary tables for the three-way ANOVA performed on the maximal force exerted at 90, 150, 210, 270 and 300°/s are presented in Appendix I-I, J-I, K-I, L-I, and M-I, respectively.

These tables revealed significant ($p < .05$) time main effects (C) at

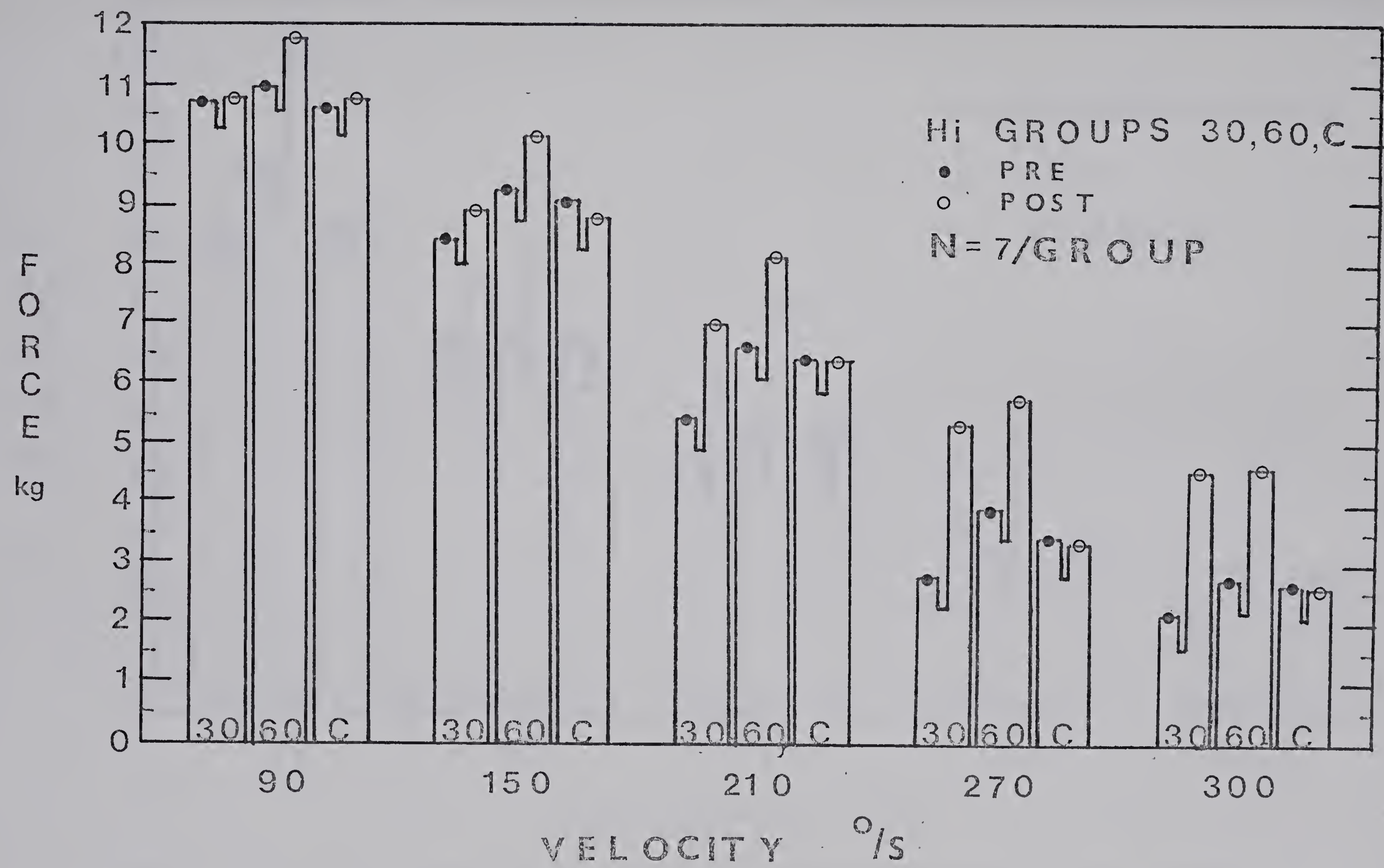


Figure 8. Pre and post-test forces at five different pre-set velocities of movement for the Hi force groups.

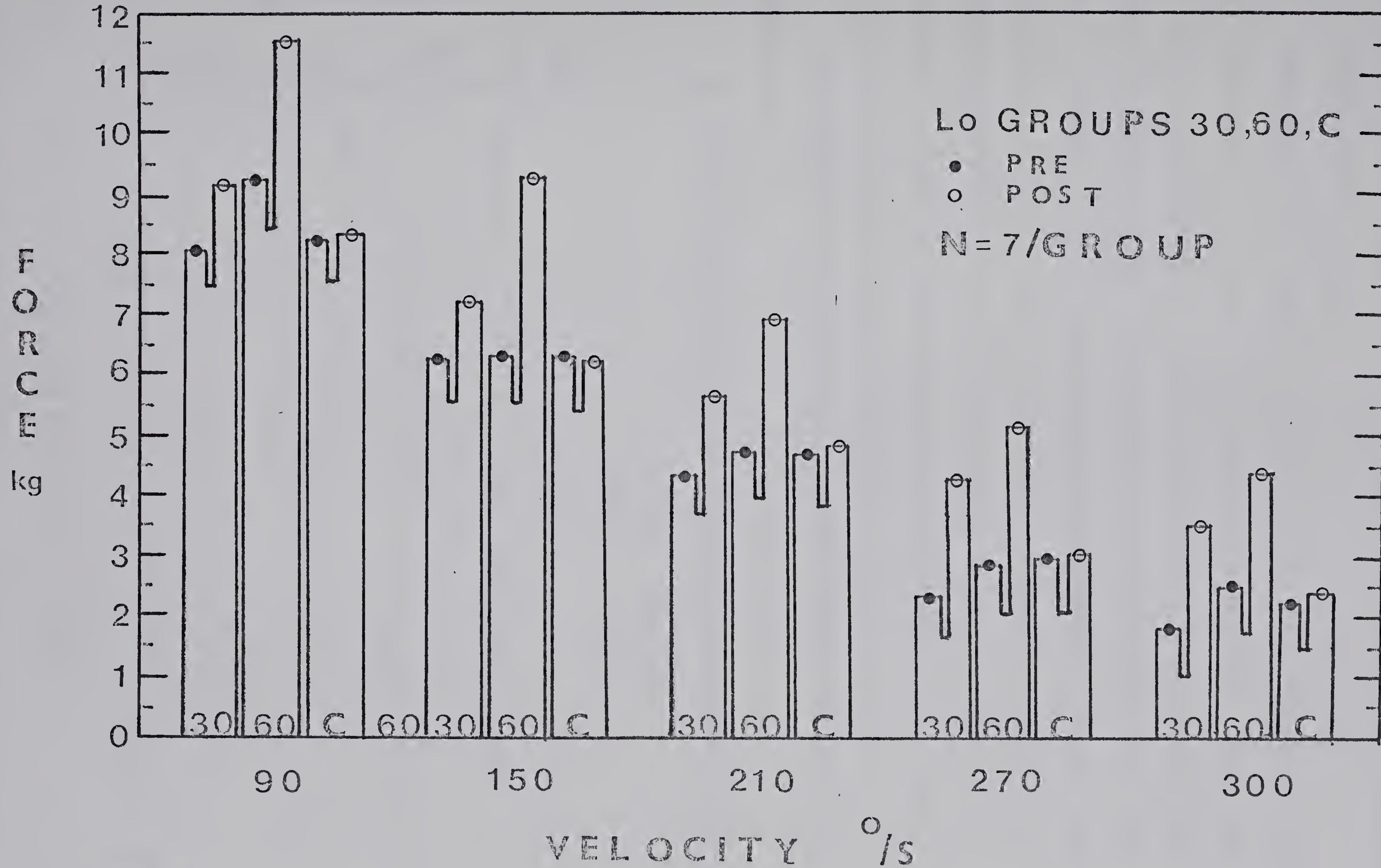


Figure 9. Pre and post-test mean forces at five different pre-set velocities of movement for the Lo force groups

all five velocities measured when collapsed over the classification (A) and treatment (B) factors.

Significant ($p < .05$) classification X time (AC) interactive effects are shown only for 90 and 150°/s (Appendix I-I and J-I). Neuman-Keuls analysis of the significant AC interactions revealed a significantly different ($p < .05$) rate of force change over time between the Hi and Lo force group at both velocities measured (Appendix I-II and J-II). Analysis of the simple main effects by one-way ANOVAS showed a significant difference ($p < .05$) in the ability to exert maximal force between the Hi and Lo force group at pretest as well as post-test velocities of 90, 150 and 210°/s (Appendix I-III, J-III and K-II.

The significant AC interactions are represented graphically in Figure 10.

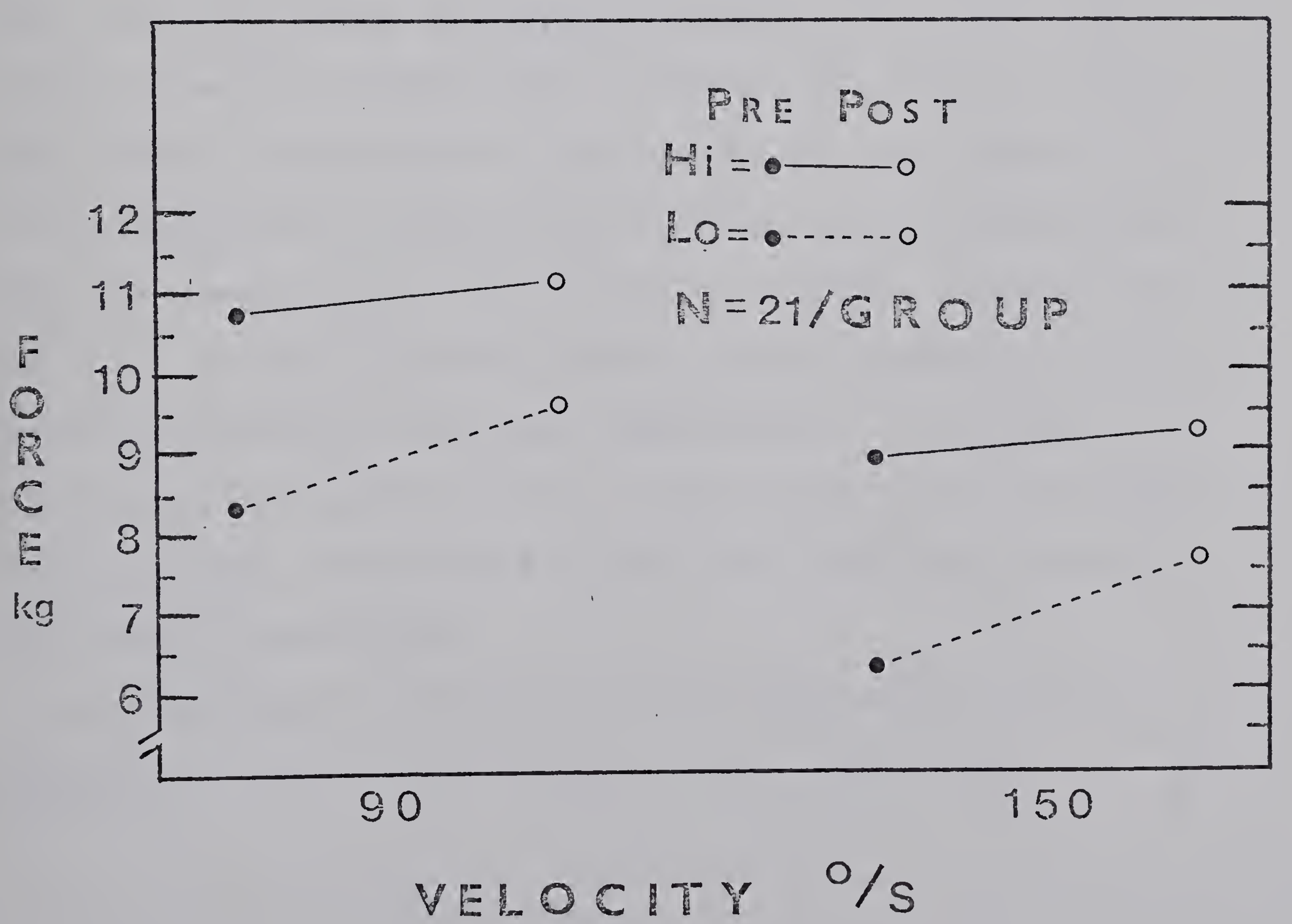


Figure 10. The significant classification X time interaction at 90 and 150°/s

Concerning the treatment X time (BC) interactive effects, the summary tables revealed significance ($p < .05$) in the maximal force exerted at all five velocities measured. Neuman-Keuls analysis of the significant BC interactions revealed that the rate of force change over time for the 60 P_o training group is significantly different ($p < .05$) from that of the control group at 90°/s (Appendix I-II). At 150°/s however, the 60 P_o training group is significantly different from the 30 P_o group as well as the control (Appendix J-IV). At the higher velocities of 210, 270 and 300°/s, the rate of force change over time in both the 30 and 60 P_o training groups is significantly different from that of the control group (Appendix K-III, L-II, M-II).

Analysis of simple main effects by one-way ANOVAS revealed a significant difference in the maximal force exerted between the 30 P_o, 60 P_o and control groups (N=14/group) only at post-test for all five velocities measured (Appendix I-V, J-V, K-IV, L-III, M-III). Neuman-Keuls analysis revealed that the post-test maximal force exerted by the 60 P_o training group is significantly different ($p < .05$) from both the 30 P_o and control group at post-test for 90 and 150°/s (Appendix I-VI and J-VI). At 210°/s, the 60 P_o training group is significantly different ($p < .05$) only to the control (Appendix K-V). At the high velocities of 270 and 300°/s, both the 30 P_o and 60 P_o training groups are significantly different ($p < .05$) from the control group (Appendix L-IV and M-IV, respectively).

The significant BC interactions are depicted graphically in Figure 11.

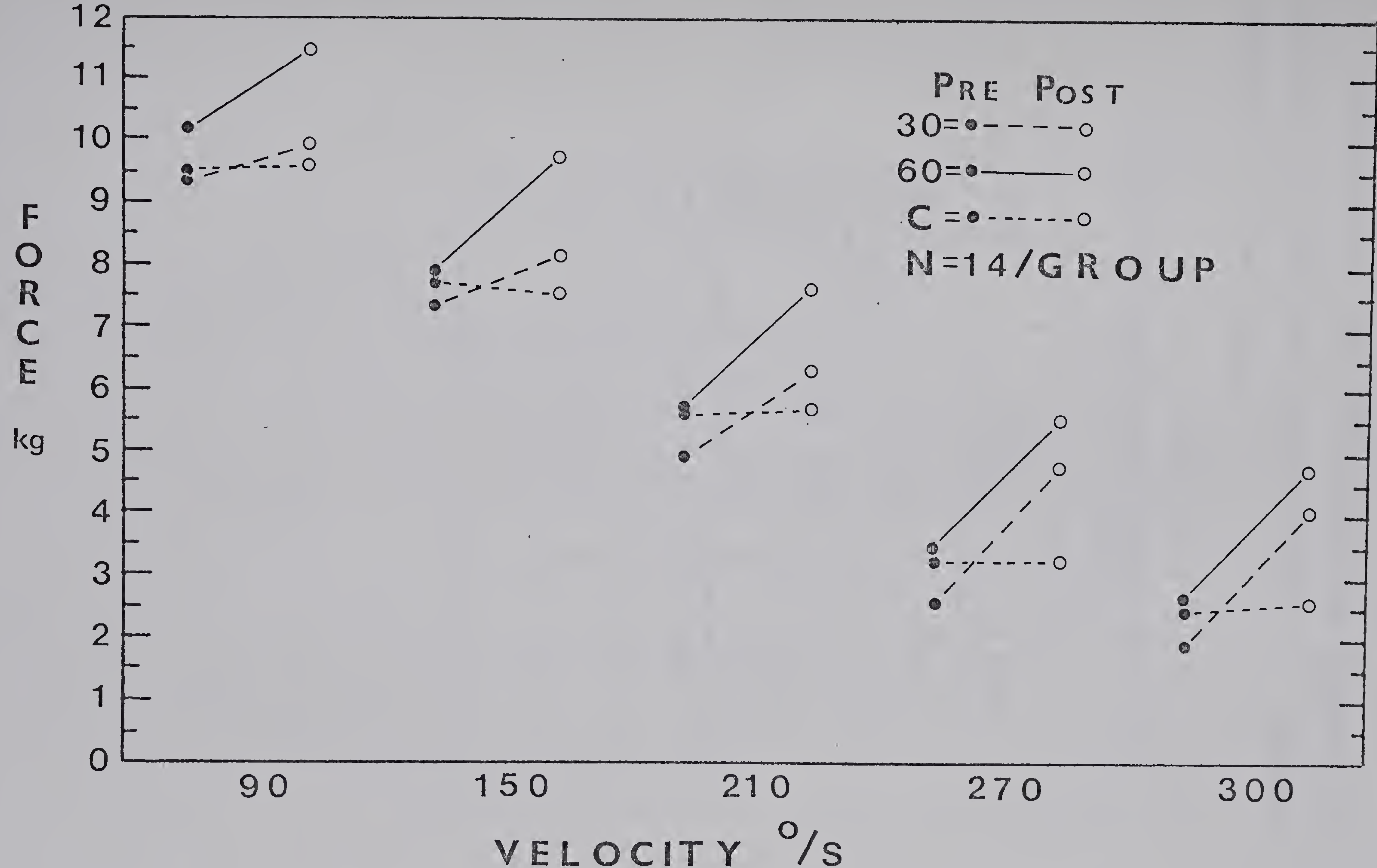


Figure 11. The significant treatment X time interaction at 90, 150, 210, 270 and 300°/s

Maximal Mechanical Power Output (MMPO)

Pre and post-test means ($\pm$SD) for peak MMPO obtained by the treatment groups (N=7/group) are displayed in Table III. A graphical representation is shown in Figure 12.

TABLE III

PRE AND POST-TEST MEAN PEAK MMPO FOR THE Hi AND Lo FORCE GROUPS (N=7/GROUP)

GROUP	PEAK MMPO kgm/s PRE	POST	% DIFF
Hi 30 P_o	5.94	7.61	28.11
SD $\pm$	1.01	1.54	
Hi 60 P_o	7.31	8.43	15.32
SD $\pm$	2.58	1.90	
Hi C	6.85	6.68	2.54
SD $\pm$	2.05	1.61	
Lo 30 P_o	4.87	6.34	30.18
SD $\pm$	1.41	1.44	
Lo 60 P_o	5.42	7.80	43.91
SD $\pm$	1.68	2.42	
Lo C	5.02	5.12	1.99
SD $\pm$	1.76	1.65	

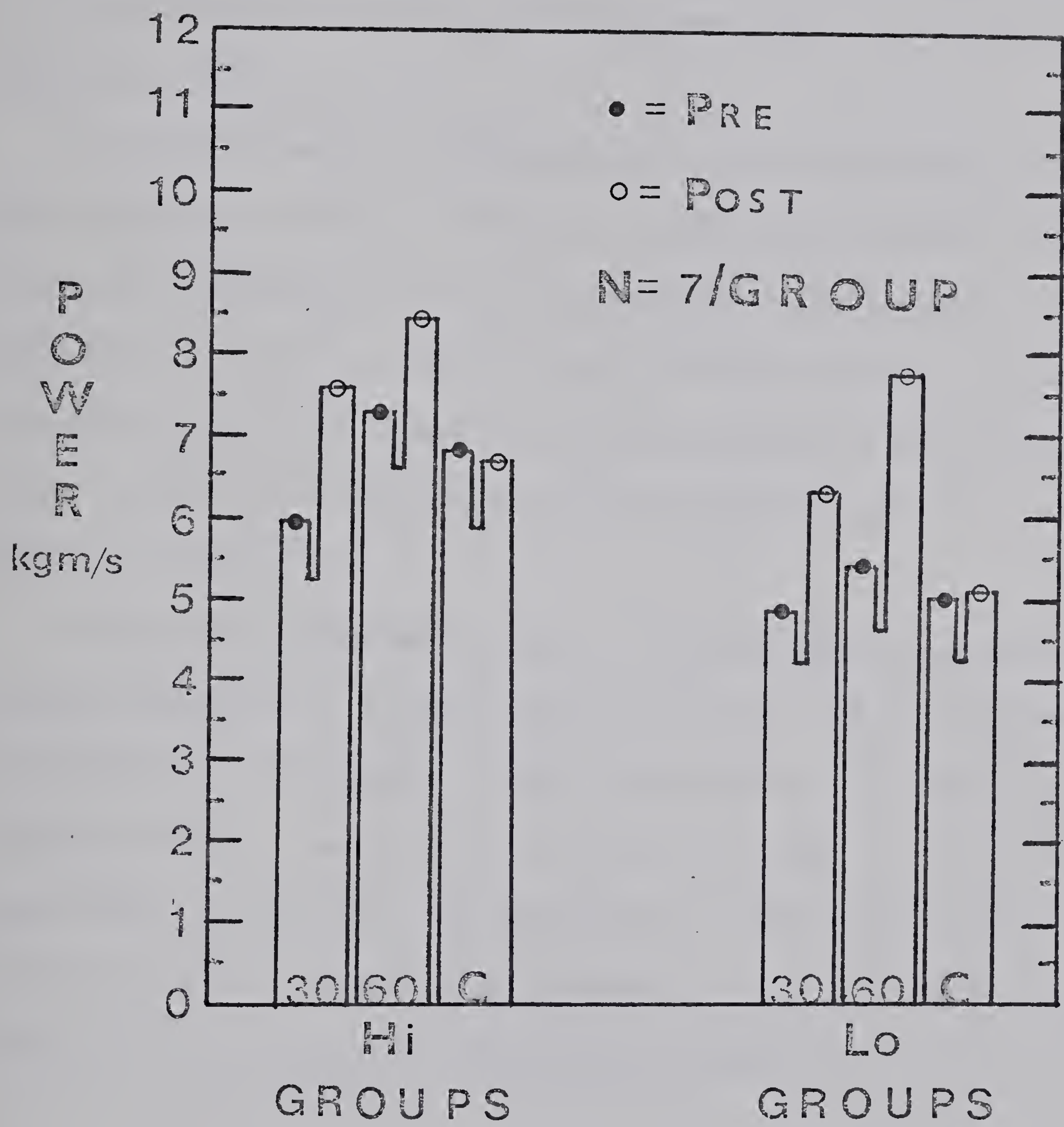


Figure 12. Pre and post-test means for peak MMPO for the Hi and Lo force groups

The summary table for the three-way ANOVA performed on the peak MMPO (Appendix N-I) revealed a significant ($p < .05$) main effect for time (C) when collapsed over the classification (A) and treatment factor (B). In addition, a significant main effect ($p < .05$) is shown for the classification factor (A) when collapsed over the treatment (B) and time factors (C).

The table showed no significant ($p < .05$) classification X time (AC) interactive effects. However, a significant ($p < .05$) treatment X time (BC) interaction is shown. Neuman-Keuls analysis of the significant BC interaction revealed that the rate of change in peak MMPO over time in both the 30 and 60 P_o training group is significantly different ($p < .05$) from that of the control group but not from each other (Appendix N-II).

Analysis of simple main effects by one-way ANOVAS revealed a significant difference ($p < .05$) between the 30 P_o, 60 P_o and control group (N=14/group) in the ability to exert peak MMPO only at post-test (Appendix N-III). Neuman-Keuls comparison of ordered post-test means showed that only the 60 P_o training group is significantly different ($p < .05$) than the control group (Appendix N-IV). The significant BC interaction is represented graphically in Figure 13.

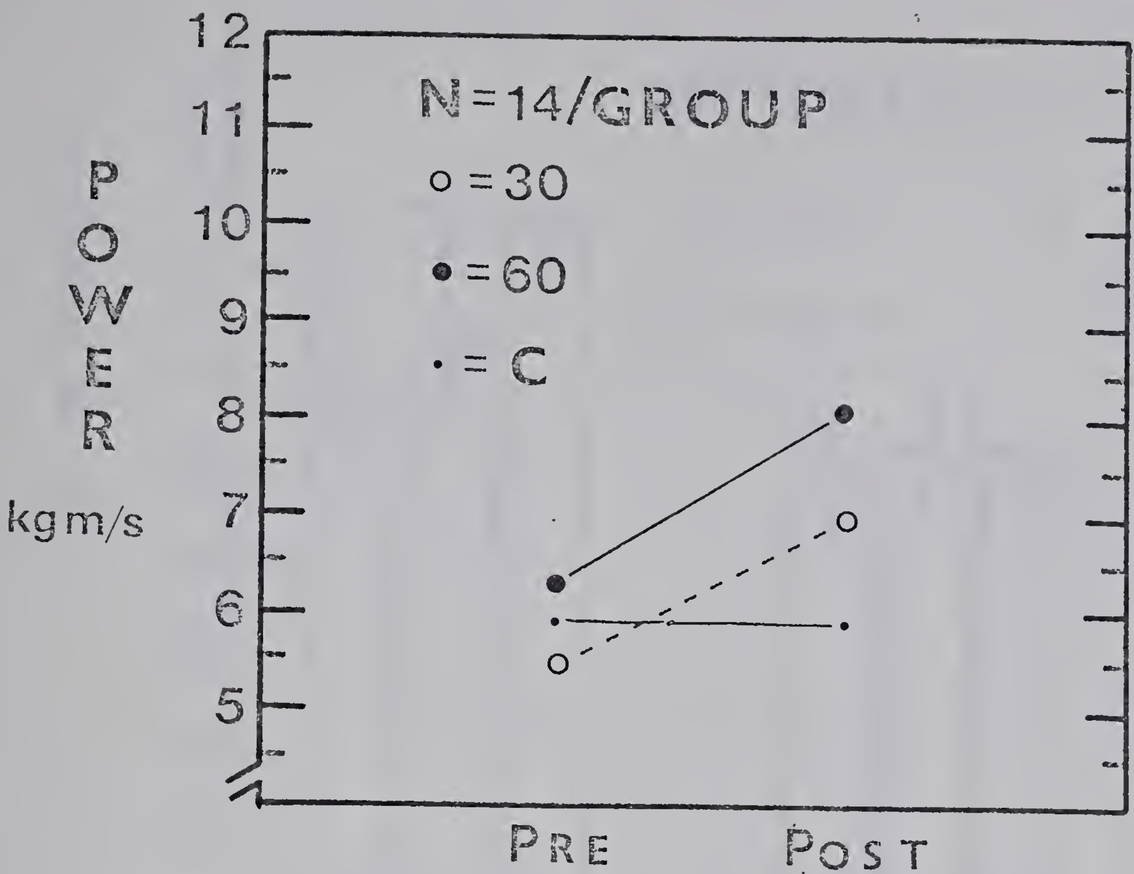


Figure 13. The significant treatment X time interaction for peak MMPO

<u>Maximal Force Exerted at Peak MMPO</u>

Pre and post-test mean forces exerted at peak MMPO by the treatment groups (N=7/group) are shown in Table IV. The pre and post-test means are depicted graphically in Figure 14.

TABLE IV

PRE AND POST-TEST MEAN FORCES EXERTED AT PEAK MMPO
FOR THE Hi AND Lo FORCE GROUPS (N=7/GROUP)

GROUP	FORCE (kg) AT PEAK MMPO PRE	POST	% DIFF
Hi 30 P_o	7.50	5.64	32.99
SD ±	0.58	0.70	
Hi 60 P_o	7.69	6.33	21.48
SD ±	0.87	0.87	
Hi C	7.67	7.67	0.0
SD ±	0.66	0.64	
Lo 30 P_o	5.54	4.94	12.15
SD ±	1.18	0.69	
Lo 60 P_o	5.21	5.94	14.01
SD ±	0.62	0.87	
Lo C	5.29	5.11	1.96
SD ±	1.35	1.09	

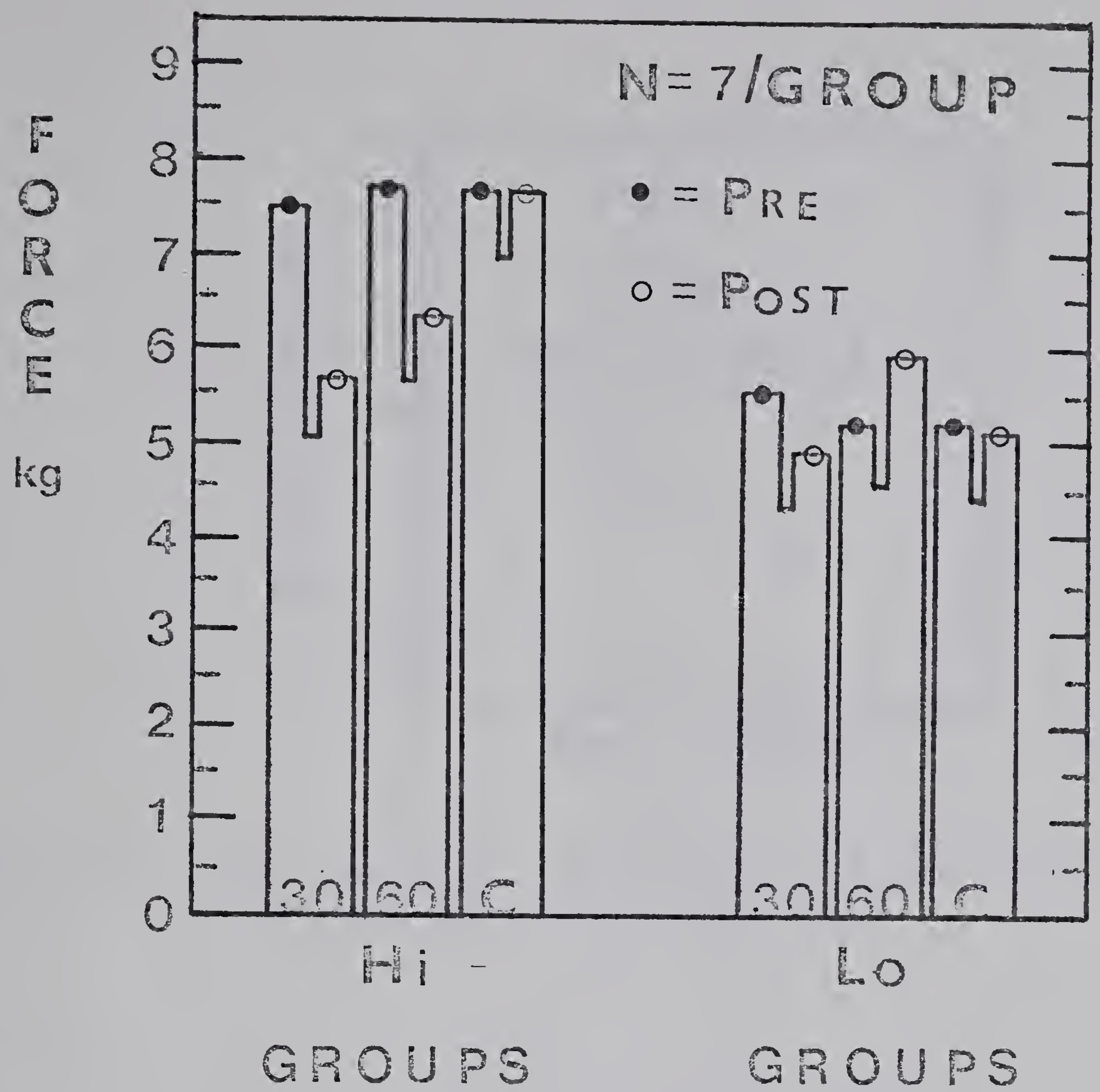


Figure 14. Pre and post-test means for the maximal force exerted at peak MMPO for the Hi and Lo force groups

The summary table for the three-way ANOVA performed on the maximal force exerted at peak MMPO revealed a significant ($p < .05$) main effect for the time factor (C) when collapsed over the classification (A) and treatment (B) factors (Appendix O-I).

The table showed a significant ($p < .05$) classification X time (AC) interaction effect. Neuman-Keuls analysis revealed a significantly different ($p < .05$) rate of change in maximal force exerted at peak MMPO over time between the Hi and Lo force group (N=21/group) (Appendix O-II). Analysis of simple main effects by one-way ANOVAS showed a significant difference ($p < .05$) in the ability to exert maximal force at peak MMPO between the Hi and Lo force group at pre-test as well as at post-test (Appendix O-III). The significant AC interaction is depicted graphically in Figure 15.

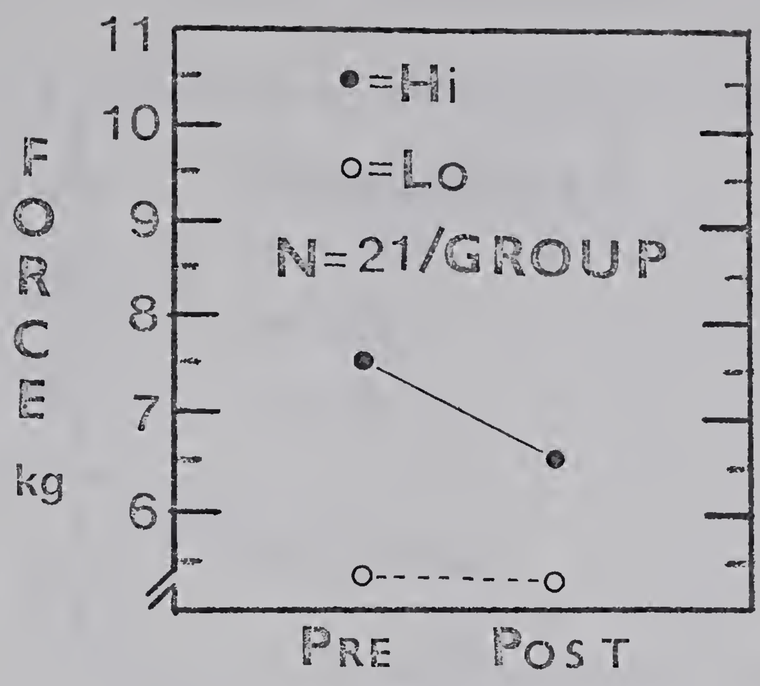


Figure 15. The significant classification X time interaction for the maximal force exerted at peak MMPO

The summary table for the three-way ANOVA performed on the maximal force exerted at peak MMPO (Appendix O-I) also revealed a significant ($p < .05$) treatment X time (BC) interaction. Neuman-Keuls analysis of the significant BC interaction showed that the rate of change in maximal force exerted at peak MMPO over time in the 30 P_o training group is significantly different ($p < .05$) from that of the 60 P_o training group as well as the control group (Appendix O-IV). Analysis of simple main effects by one-way ANOVAS showed that a significant difference ($p < .05$) existed only at post-test between the 30 P_o, 60 P_o and control groups in the ability to exert maximal force at peak MMPO (Appendix O-V). Neuman-Keuls comparison of ordered post-test means revealed that only the 30 P_o training group is significantly different ($p < .05$) from the post-test control group in the maximal force exerted at peak MMPO

(Appendix O-VI). The significant BC interaction is show in Figure 16.

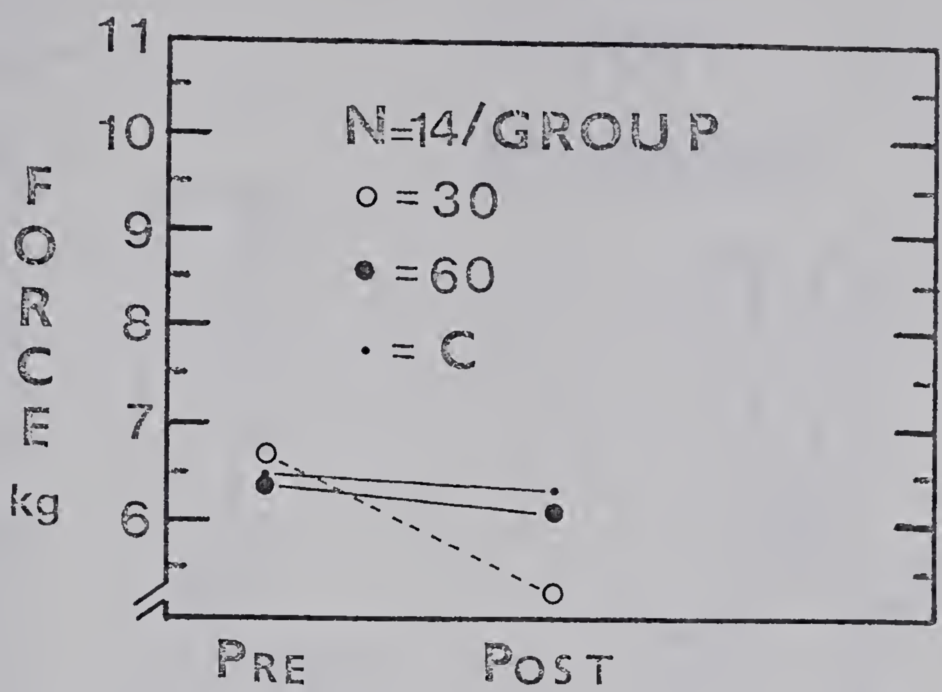


Figure 16. The significant treatment X time interaction for the maximal force exerted at peak MMPO

Maximal Velocity at Peak MMPO

Pre and post-test means (±SD) for the maximal predicted velocities attained at peak MMPO for the treatment groups (N=7/group) are shown in Table V and Figure 17.

TABLE V

PRE AND POST-TEST MEAN MAXIMAL PREDICTED VELOCITIES EXERTED AT PEAK MMPO FOR THE Hi AND Lo FORCE GROUPS (N=7/GROUP)

GROUP	VELOCITY (m/s) AT PEAK MMPO PRE	POST	% DIFF
Hi 30 P_o SD ±	0.795 0.15	1.361 0.28	71.19
Hi 60 P_o SD ±	0.957 0.40	1.351 0.32	41.17
Hi C SD ±	0.898 0.29	0.882 0.27	1.13
Lo 30 P_o SD ±	0.913 0.31	1.308 0.28	43.26
Lo 60 P_o SD ±	1.066 0.40	1.311 0.35	22.98
Lo C SD ±	0.951 0.19	1.000 0.21	5.15

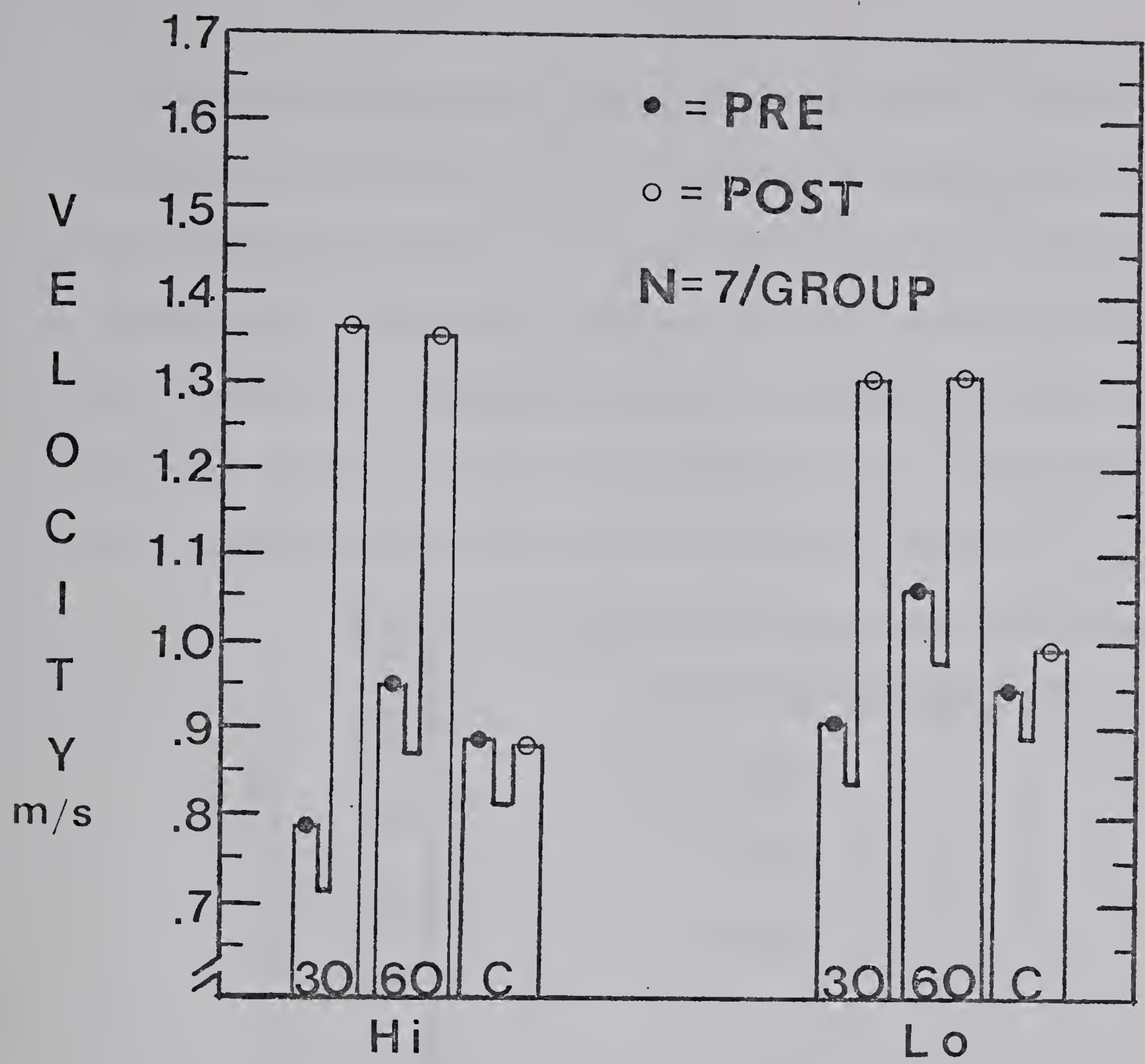


Figure 17. Pre and post-test means for the maximal velocity exerted at peak MMPO

The three-way ANOVA performed on the maximal velocity at peak MMPO revealed a significant ($p < .05$) main effect for the time factor (C) when collapsed over the classification (A) and treatment factor (C) (Appendix P-I).

Non-significant ($p < .05$) classification X time (AC) interactive effects are shown. However, significant ($p < .05$) treatment X time (BC) interaction is revealed. Neuman-Keuls analysis of the significant BC interaction showed that the rate of change in the maximal velocity at peak MMPO over time in the 30 P_o and 60 P_o group is significantly different ($p < .05$) from that of the control group (Appendix P-II).

Analysis of simple main effects by one-way ANOVAS revealed a significant difference ($p < .05$) in the maximal predicted velocity exerted at post-test between the 30 P_o, 60 P_o and control group (Appendix P-III). Neuman-Keuls analysis of ordered post-test means showed that both the 30 P_o and 60 P_o training groups are significantly different ($p < .05$) from the control group but not different from each other (Appendix P-IV). The significant BC interaction is shown in Figure 18.

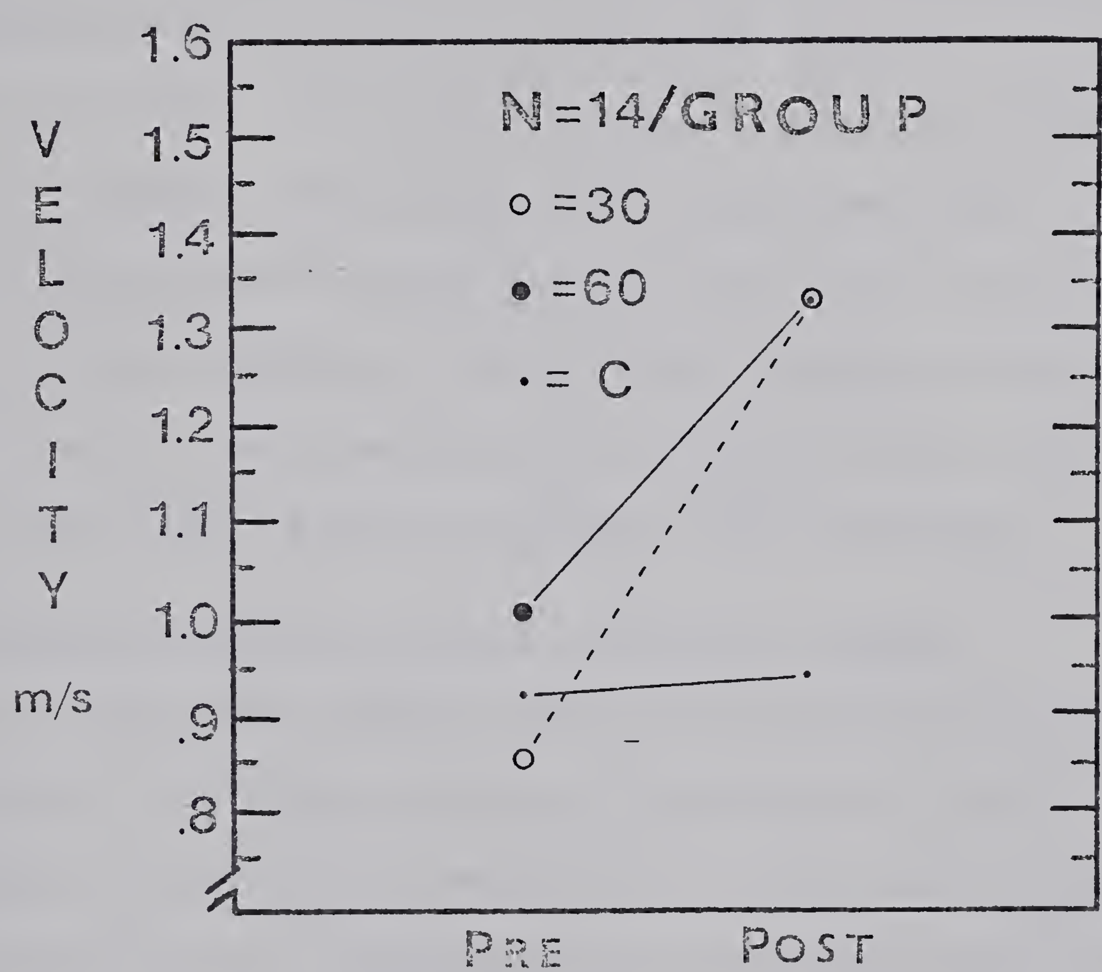


Figure 18. The significant treatment X time interaction for the maximal velocity exerted at peak MMPO

Maximal Isometric Force (P_o)

No significant ($p < .05$) interactive or main effects are revealed in the summary table for the three-way ANOVA performed on the maximal isometric force (P_o). Hence, no further analysis is justified (Appendix Q-I).

Pre and Post-Test Composite F-V-P Curves

Pre and post-test F-V-P relationships are shown for the Hi force groups in Figures 19, 20 and 21 and for the Lo force groups in Figures 22, 23 and 24. It is interesting to note, that little alteration has occurred in the Hi and Lo force control groups (Figure 24 and 21 respectively). Three of the four training groups (Hi 30 P_o, Hi 60 P_o and Lo 30 P_o) displaced the upper portion of the F-V curve to a greater extent and consequently, the generation of peak power at post-test has shifted slightly to the left. For these three groups, post-test peak power occurred at a higher velocity with a lower force generation. Only the Lo 60 P_o training group displaced the F-V curve in an "all round" manner with the subsequent shifting of the post-test peak power slightly to the right. In essence, the generation of post-test peak power for this group took place at a higher velocity and higher force generation.

Maximal Isometric Force at 100, 120, 140 and 160 Degrees

The three-way ANOVA summary tables for the maximal isometric force (P_o) performed at an elbow angle which corresponded to 100, 120, 140 and 160 degrees are shown in Appendix R-I, II, III, and IV, respectively. Only one significant ($p < .05$) main effect for the time factor (C) when collapsed over the treatment (B) and classification factor (A) is revealed (Appendix R-I). All other interactive and main effects are non-significant ($p < .05$).

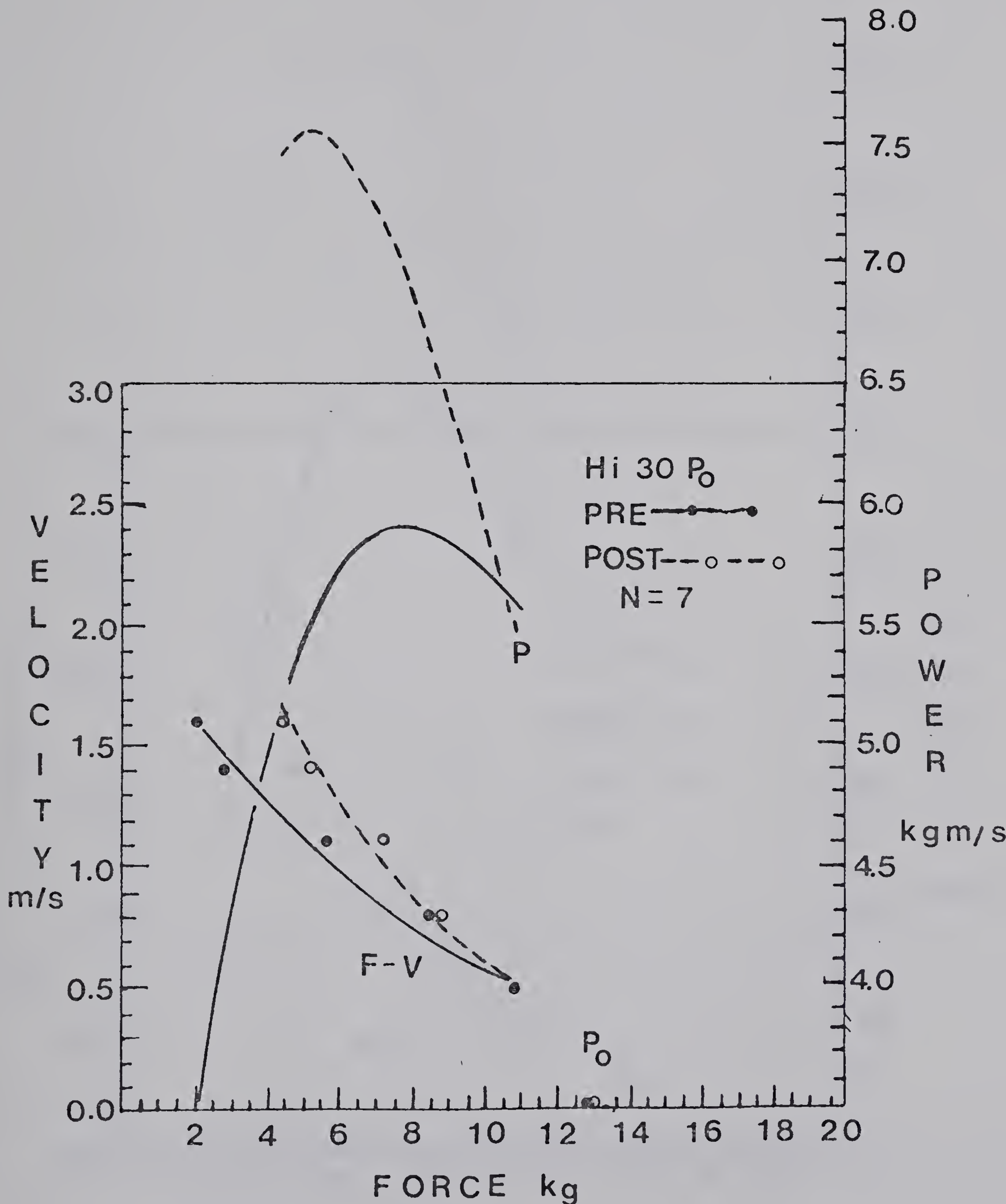


Figure 19. Composite pre and post-test force-velocity-power relationship for the Hi 30 P_o training group as derived by isokinetic measurement. Experimental points obtained from mean force-velocity values.

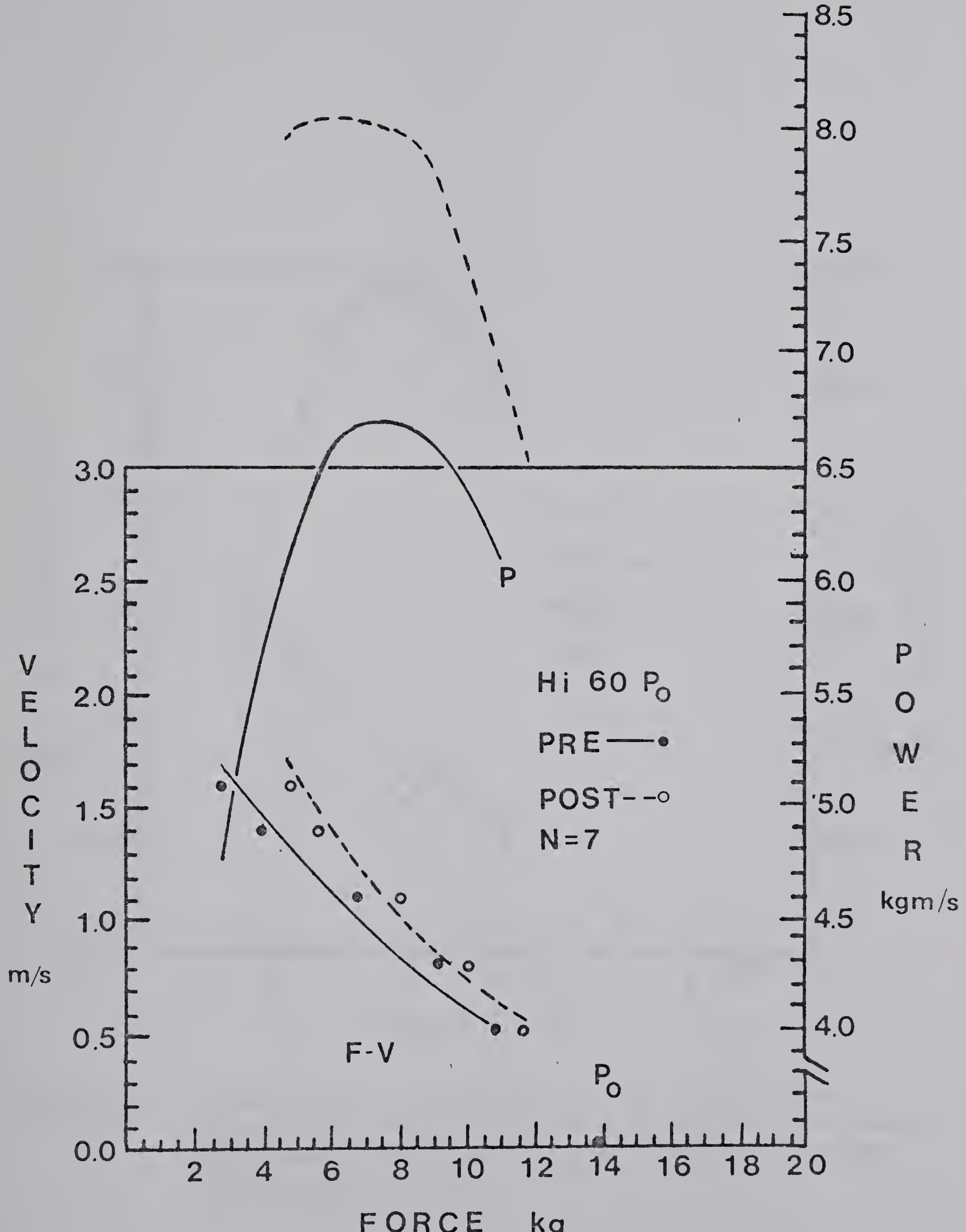


Figure 20. Composite pre and post-test force-velocity-power relationship for the Hi 60 P_o training group as derived by isokinetic measurement. Experimental points obtained from mean force-velocity values.

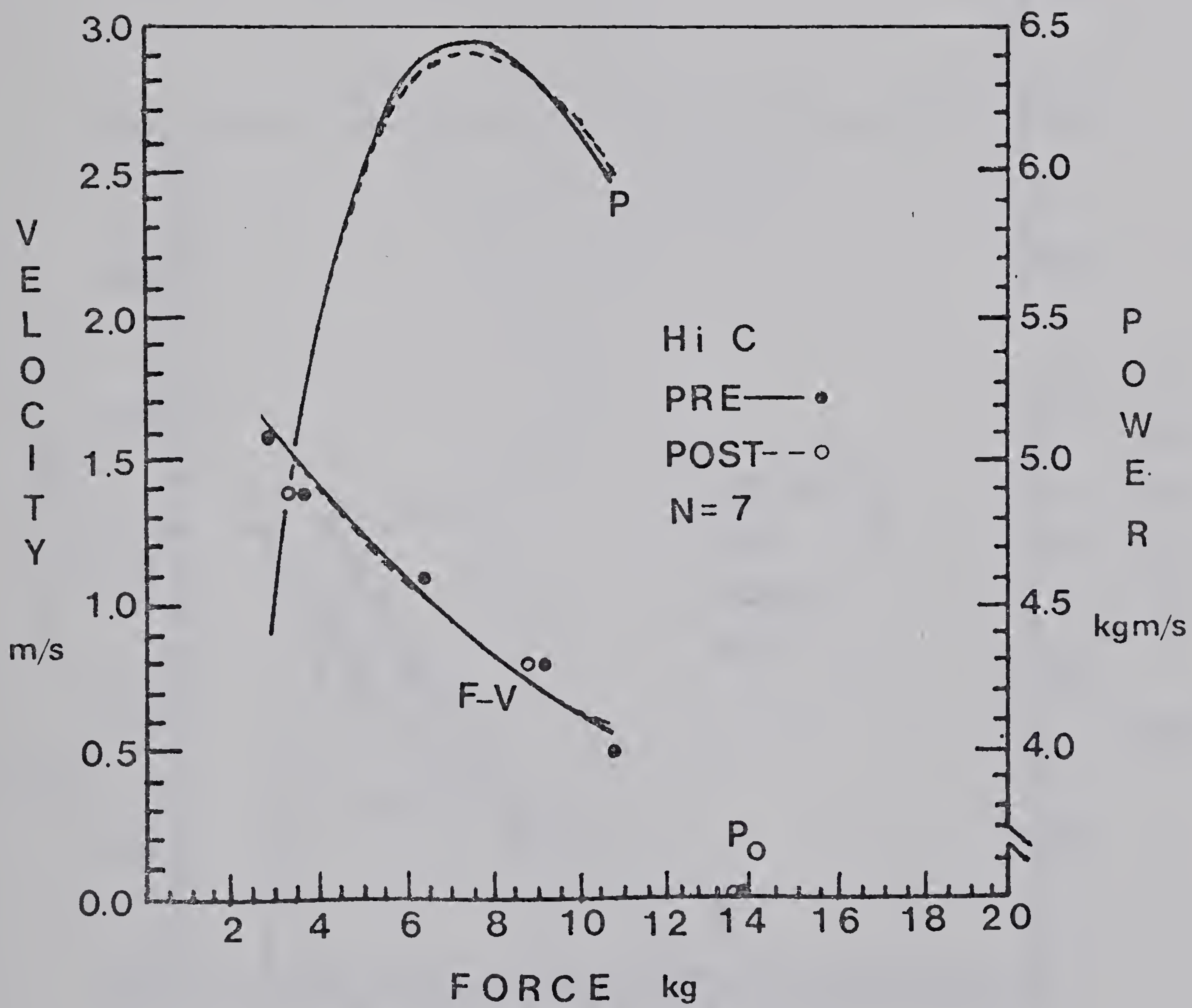


Figure 21. Composite pre and post-test force-velocity-power relationship for the Hi C group as derived by isokinetic measurement. Experimental points obtained from mean force-velocity values.

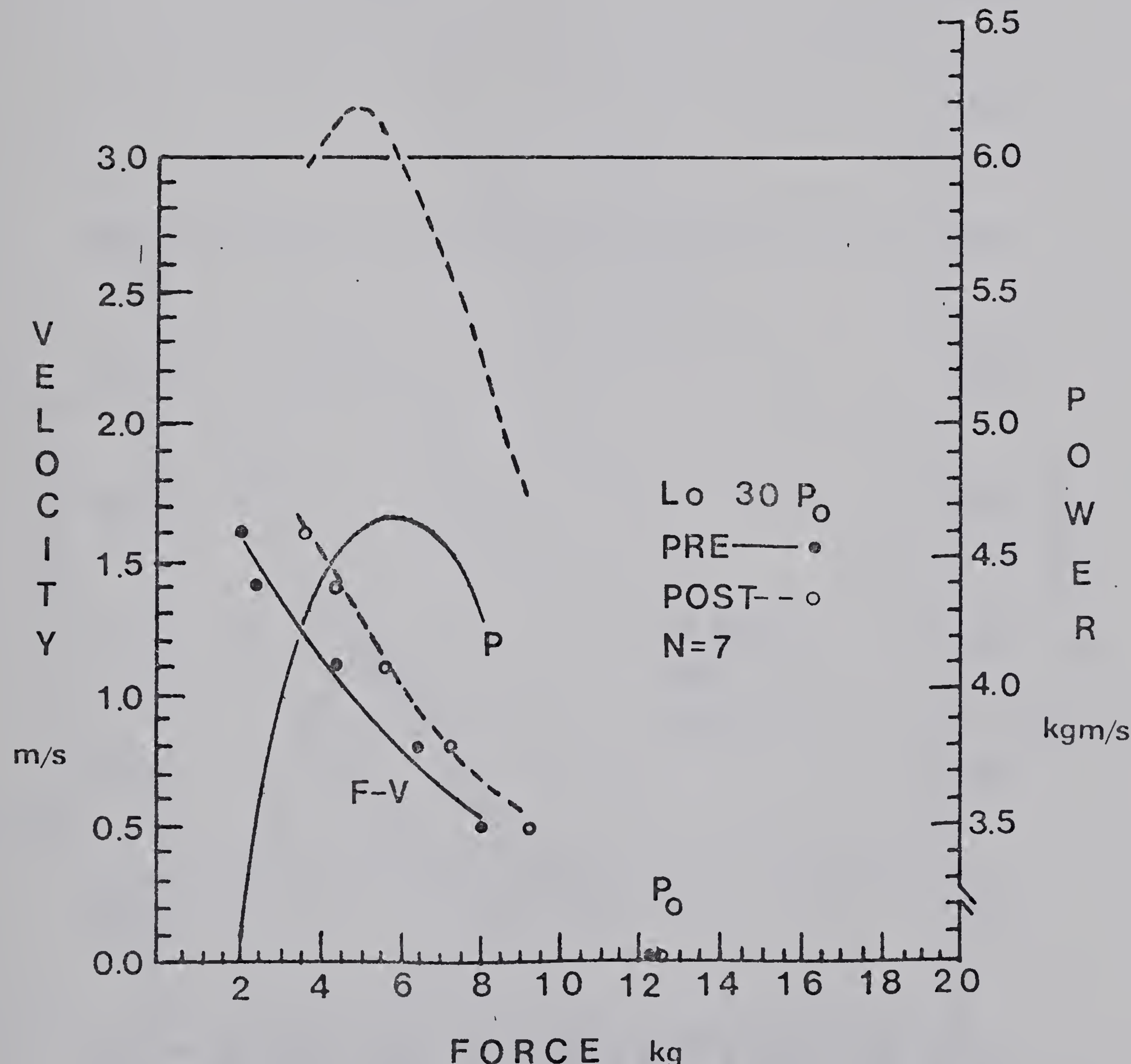


Figure 22. Composite pre and post-test force-velocity-power relationship for the Lo 30 P_o training group as derived by isokinetic measurement. Experimental points obtained from mean force-velocity values

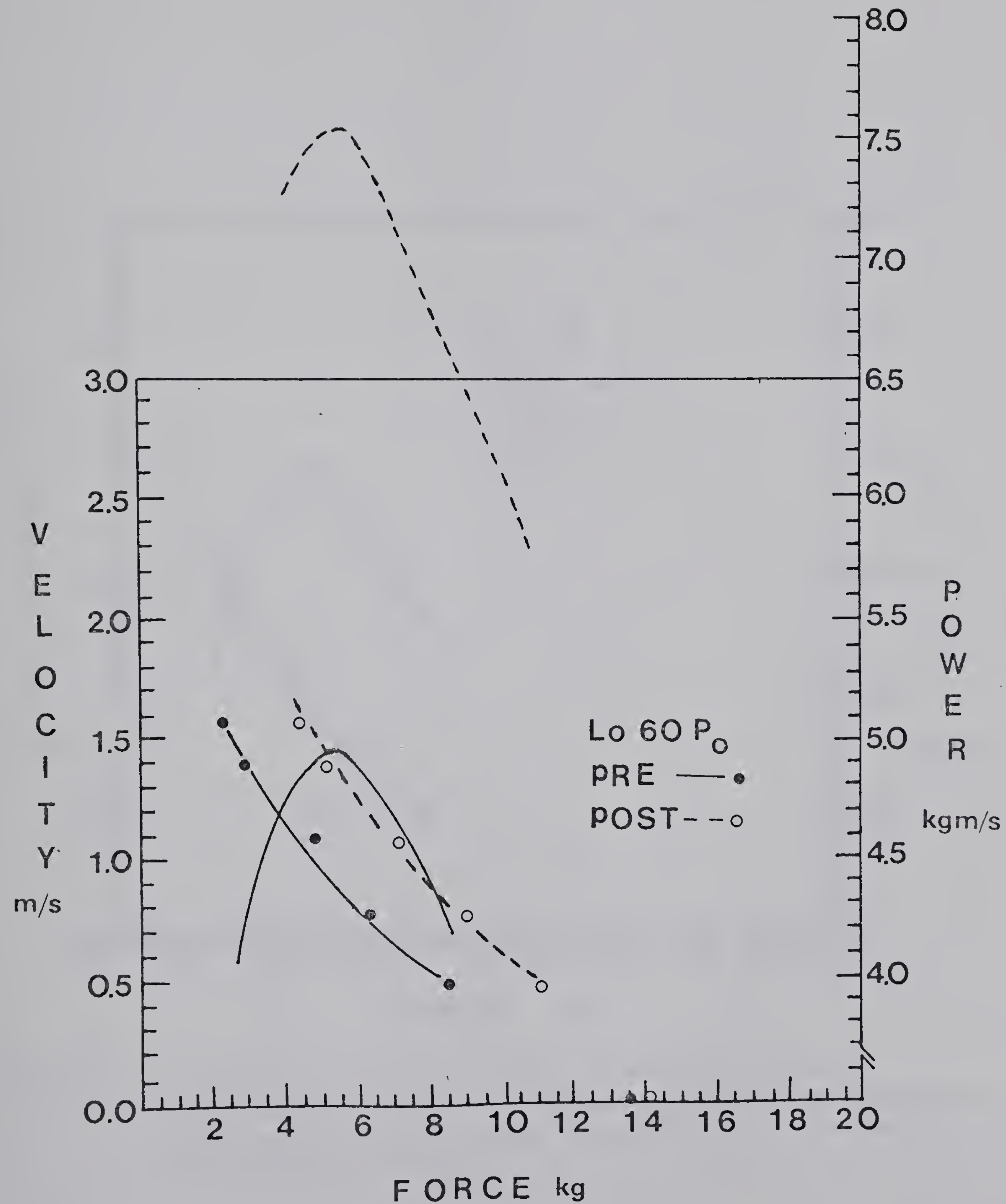


Figure 23. Composite pre and post-test force-velocity-power relationship for the Lo 60 P_o training group as derived by isokinetic measurement. Experimental points obtained from mean force-velocity values.

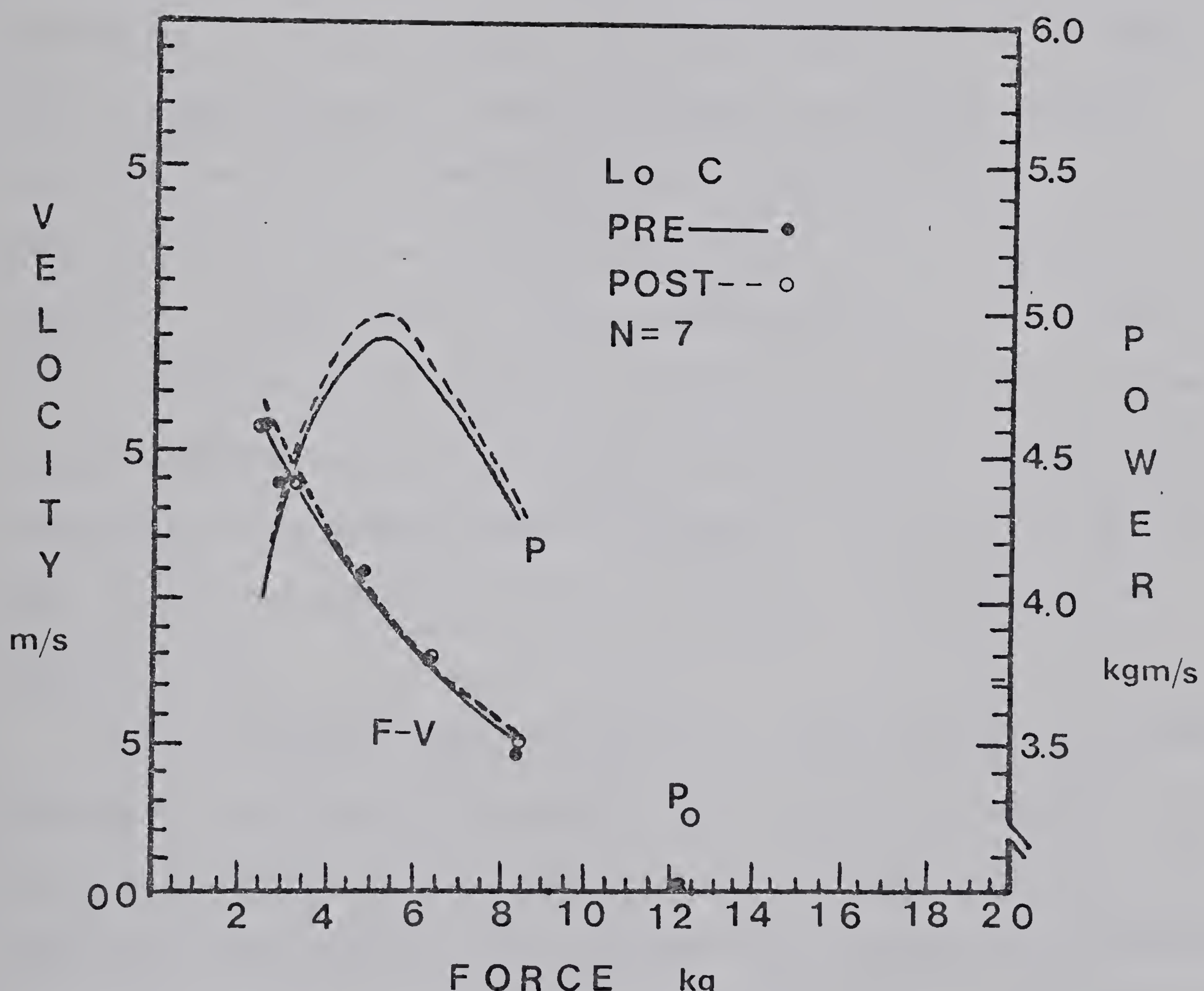


Figure 24. Composite pre and post-test force-velocity-power relationship for the Lo C group as derived by isokinetic measurement. Experimental points obtained from mean force-velocity values.

CHAPTER V

DISCUSSION

It has been speculated that F-V curves derived by isokinetic measurements are "similar to the first third of the classic curve derived for all velocities up to the maximal velocity (71)". Examination of Figure 5 however, reveals that Hill's theoretical isotonic curve does not fit the observed isokinetic data at the higher and lower ends of the curve; predicting higher and lower F-V values respectively. In this regard, it must be mentioned that the constants a and b derived for Hill's equation were obtained by graphical means and "it is sometimes impossible to derive the constants from the observed curve with any reasonable degree of accuracy. This is due to the fact that the observed curve forms only a section of the theoretical hyperbola." (51)

While a relatively small difference (.2 Kgm/s) exists in peak MMPO between the two methods, the maximal force exerted at peak MMPO to P_o is quite different. The isotonic ratio of .34 agrees closely to .35 reported by Ikai (43) and .33 by Kawahatsu (52) for isotonic measurements. The isokinetic ratio of .50 supports the higher ratio of .56 obtained by Osternig (76) for isokinetic measurements. The reason for the discrepancy between the two methods may possibly be sought in the lower than normally expected P_o value of 13.09 Kg reported in this study and supported by other submaximal isokinetic measurements of P_o (70,76). Indeed, extrapolation of the isokinetic F-V curve to zero velocity

predicts a P_o value of approximately 18 Kg and reduces the ratio from .50 to .36.

Projecting the isokinetic F-V curve to zero force and using a predicted V_{max} of 3.25 as shown for human arm movements of untrained adult females (43), the ratio of maximal velocity at peak MMPO to V_{max} is .25 and is slightly lower to ratios obtained isotonically (43,56).

If the value of 13.09 Kg represents the P_o value accurately and is not a function of the isokinetic measuring device, then F-V curves derived isokinetically may not be represented accurately by Hill's isotonic curve and casts some doubt on the reported equal percentages of maximal force and velocity at peak MMPO to their maximum values in intact human muscle.

The classification of Hi and Lo maximal force generators at peak MMPO is critical to this investigation. Examination and comparison of the pretest F-V-P relationships derived for the Hi and Lo force group in figures 6 and 7 reveals a significant difference between the two groups in the ability to exert maximal force at peak MMPO. In addition, the Hi and Lo force groups are significantly different at pretest in the maximal force generation at the three lower velocities measured. The fact that a non-significant difference in the maximal force production exists between the two classifications at the two higher velocities measured and at maximal isometric force may suggest equality between the two groups at the extreme ends of the F-V curves. However, the significant pretest difference ($p < .05$) between the two groups in the maximal force exerted at peak MMPO under dynamic conditions reinforces the importance of utilizing the maximal force exerted at peak MMPO as a classification factor. This is strengthened by the non-significant pretest

difference in the predicted maximal velocity of movement at peak MMPO between the Hi and Lo force group.

The maximal force-velocity training interactions derived for each individual specific to the treatment applied (Table I) illustrates the uniqueness of the isokinetic training method to the researcher. That is, that very specific force-velocity training interactions can be assigned to each individual while maintaining the same relative training stimulus within a group. In isotonic training however, the control of the absolute training values are less certain as the maximal training force and velocity of movement are complicated by additional factors of inertia, acceleration and gravity (21,90). In this study, only one subject (#25) had a calculated maximal training velocity outside the limits of the Cybex. In this case, the maximal training velocity was reduced from 315 to 300°/s.

The primary purpose of this investigation was to evaluate the effects of two different force-velocity training interactions on alteration of the force-velocity relationship and peak MMPO produced by the contracting forearm flexor muscles. Therefore, the composite pre and post-test F-V-P relationships derived for the treatment groups in Figures 19, 20, 21, 22, 23 and 24 must be examined and interpreted.

It is evident from figures 21 and 24 that the F-V-P relationships derived for the Hi and Lo control groups appear quantitatively similar from pre to post-test. Reliability coefficients obtained from duplicate determinations at pre-test for the five pre-set velocities were high (.90 to .97)(Appendix H-III). This supports previous research (71).

The F-V relationships derived for the four training groups in Figures 19, 20, 22 and 23 show definite alterations in maximal force

from pre to post-test. The faster rate of force change over time exhibited by the Lo force group at the two slowest velocities measured (Figure 10) may well be anticipated in light of the significant pretest difference between the two groups. In addition, the 60 P_o force-velocity training interaction provides a faster rate of force change over time at these two slower velocities (Figure 11). This evidence strongly suggests that the 60 P_o force-velocity training interaction is more effective in alteration of the F-V curve at the lower end (150°/s or below) and is supported by the fact that only the 60 P_o training group is significantly different from both the 30 P_o and control group at post-test. Inspection of the pre and post-test mean forces obtained by the treatment groups in Figures 8 and 9 for the two slowest velocities measured (90 and 150°/s), show greater percentage increases made by the 60 P_o training in both the Hi and Lo force groups.

Considering the alteration of the maximal force exerted at the middle velocity measured (210°/s), no significant difference exists in the rate of force change over time between the Hi and Lo force group. This is somewhat puzzling as a significant difference still exists between the Hi and Lo force generators at pretest and a greater response might well be expected from the Lo force generators. However, examination of Figure 11 at 210°/s reveals that the rate of force change over time is not significantly different between the 30 and 60 P_o training groups. This initially suggests that both force-velocity training interactions are effective in alteration of the F-V curve at the middle velocity. Examination of the pre and post-test mean forces obtained of the treatment groups in Figures 8 and 9 supports this and for the first time, suggests that the 30 P_o force-velocity training interaction may be

more effective for the Hi force generators.

Regarding the force increases at the two highest velocities measured (270 and 300°/s), no significant differences exist in the rate of force change over time between the Hi and Lo force groups. In addition, no significant difference exists in the rate of force change over time between the 30% and 60% treatment groups. Obviously, non-significant main effects for the classification factor as well as the treatment factor contribute to the similarity in responses. Another contributing factor may be the suggestion of an increased dependence on the myosin ATPase activity rather than the number of actin-myosin interactions at higher velocities (50). The mean forces obtained at 270 and 300°/s (Figure 8 and 9) support the previous suggestion that Hi force generators respond more effectively to the 30 P_o training stimulus at velocities of 210°/s up to a maximum of 300°/s.

The percentage increases in maximal force exerted at the higher velocities (Table II) seem dramatic but increases of 78.9% have been reported for isokinetic training at 136°/s (78).

The alterations of the composite F-V curves for the four training groups reflect pre to post-test changes in peak MMPO. It is interesting, that the pre-test peak MMPO occurs in all treatment groups between 150 and 210°/s and the question arises as to which force-velocity training interaction is more effective in alteration of peak MMPO. Although a significant main effect for the time factor is revealed for peak MMPO, no significant difference exists in the rate of change in peak MMPO over time between the Hi and Lo force group in spite of a significant pre-test difference. This suggests equality of responses to the two different force-velocity training interactions regardless of the

classification. Indeed, inspection of Figure 13 supports this by revealing that both the 30 and 60 P_o treatments are significantly different from the control in the rate of change in peak MMPO over time but not different from each other. However, the percent differences from pre to post-test in Table III show a greater increase (28.11) made by the Hi force group training at 30 P_o while the Lo force group shows slightly a greater increase (43.91) with the 60 P_o training stimulus.

A sub-purpose of this investigation was to evaluate the effects of the two different force-velocity training interactions on the maximal force and velocity exerted at peak MMPO in individuals who possess different initial levels of maximal force at peak MMPO.

Figure 15 reveals a significantly different rate of maximal force change at peak MMPO over time between the Hi and Lo force group. Clearly, the Hi force group is decreasing more rapidly although a significant difference still exists between the two groups at post-test. In Figure 16, the 30 P_o training stimulus provides a faster rate of maximal force change at peak MMPO over time. Examination of the individual group means in Figure 14 supports this and shows that three of the four groups decreased their maximal force exerted at peak MMPO. The most probable explanation for the decrease lies in the greater shifting of the upper end of the F-V curves. Inspection of the composite F-V curves in Figures 18, 19 and 20 substantiates this and reveals that the peak MMPO has shifted to the left. In essence, the generation of peak MMPO now takes place at higher velocities because of an increased ability to produce greater maximal forces at the higher velocities. Only the Lo 60 P_o training group displayed a concomittant increase in the maximal force and velocity exerted at peak MMPO. Consequently, the peak MMPO

is shifted slightly to the right in Figure 22. It seems apparent, that the better "all round" alteration of the F-V curve is the major contributing factor to the increased maximal force and velocity at peak MMPO.

That the maximal velocity exerted at peak MMPO has shifted to higher predictive values is apparent in Figure 17. The rate of change in the maximal velocity at peak MMPO over time in both the 30 and 60 P_o treatments is significantly different from the control (Figure 18). The slightly slower rate of change in the 60 P_o treatment can be attributed to the lower percent increase (22.98) shown by the Lo 60 P_o group in Table V. The individual group means in Figure 17 supports this conjecture.

The implications derived in this study for the physical educator and coach are as follows. Regardless of whether an individual generates Hi or Lo maximal force at peak MMPO, a better "all round" alteration of the F-V curve takes place with the 60 P_o training stimulus. This is evident from viewing the composite F-V curves in Figures 20 and 23. This finding agrees with earlier work by Ikai (43) suggesting that both 30 and 60 P_o training produce all round displacement of F-V curves. However, this happens only in Lo force generators (Figures 22 and 23) and not in the Hi force generators training with the 30 P_o training stimulus (Figure 19). Therefore, it may be suggested that athletes be trained isokinetically at a maximal velocity corresponding to a maximal force production of 60 percent of the maximal isometric force when the coach is unsure of where the athlete is working on the F-V curve. The 60 P_o training stimulus is especially indicated if the athlete is developing MMPO with higher forces and lower velocities (ie. below 150°/s). On the other hand, when the athletic event demands explosive limb

movements in excess of 210°/s up to a maximum of 300°/s, then isokinetic training at a maximal velocity of movement corresponding to a maximal force production of 30 percent of the maximal isometric force appears slightly more effective for both Hi and Lo force generators. If the objective of the training is simply to increase the peak MMPO then a differential training stimulus is indicated for Hi and Lo force generators (30 and 60 P_o respectively).

The significant pre-test differences between the Hi and Lo force generators in the maximal force exerted at peak power, at 90, 150, and 210°/s may be the result of variation in muscular mass, fiber composition and/or selective recruitment of motor units. The non-significant pre-test difference in maximal isometric force (P_o) tends to exclude muscular volume as a predominating factor. However, the Hi force generators may be hereditarily gifted with a higher percentage of fast twitch (FT) fibers and consequently, be able to recruit and exert more force at these three lower speeds as well as maximum force at peak power. It is interesting to note in figures 6 and 7 that the pre-test maximal force exerted at peak power occurs between 150 and 210°/s for both groups. In this respect, Thorstensson et al. (89) have demonstrated high correlations between peak torque produced isokinetically at 180°/s and percent as well as relative area of FT fibers.

Increases in the cross-sectional area of the flexor muscles as a result of the training program are doubtful. Ikai and Fukunaga (45) failed to show hypertrophy of the forearm flexor muscles after 20 consecutive days of isometric training using ultrasonic photography. However, significant increases in strength were observed at the same time period.

If the above speculations regarding the differences in hereditary

and selective recruitment pattern are tenable, then the isokinetic training effects will reflect these differences. The faster rate of force increase exhibited by the Lo force generators with the 60% force-velocity training interactions at 90 and 150°/s may be the result of a greater training stimulus being placed on a lower percentage of FT fibers and the lower physiological starting point (Table II). Both the Hi and Lo force training groups responded more effectively to the 60% training stimulus at these two slower velocities (90 and 150°/s) and may be the result of the specificity of the training stimulus. In this respect, the mean training velocities (Table I) for both the Hi 60 P_o and Lo 60 P_o are 150 and 111°/s respectively.

The differential response of the Hi and Lo force generators to the 30 and 60% training stimuli at 210°/s and at peak power may be attributed to the ability of the Hi force generators to "switch" to a different selective recruitment pattern of FT fibers sooner than the Lo force generators. It has been suggested that "some actions requiring very forceful and/or rapid contractions may involve selective activation of fast twitch units, a reversal of the more usual order of recruitment" (6). It may be hypothesized that two patterns of selective activation of fast twitch fibers may be involved, one that requires force and the other that requires velocity.

The Lo force generators "switch" and respond to the 30 P_o training at 270 and 300°/s slightly more effectively than to the 60 P_o stimulus. Again, the specificity of the training stimulus may be a contributing factor. The mean training velocities for the Lo 30 P_o and Hi 30 P_o are 225 and 253°/s respectively.

With the recent advances in isokinetic dynamometers that allow the training of muscular forces at velocities that vary from 0 to 300°/s, it is now possible for the coach to match the velocity of training to the particular speed of performance in an athletic event. This may be extremely important in view of the recent work concerning the specificity of training (70).

It was originally intended to extend the training period to 6 weeks. However, the decision was made to reduce the number to 5 weeks in order to complete the post-test prior to the final examinations. Failure to make this decision would have resulted in greater attrition and perhaps cancellation of the experiment as many subjects were leaving the Province of Alberta for summer employment as soon as the examinations terminated. This reduction of the training period does not represent any serious threat to the interpretation of the training effect. Extremely significant increases in maximal torque production by isokinetic training have been shown (71) for four weeks of training, and consequently, it was felt justified under the circumstances to complete the experiment with five weeks of training rather than terminate the experiment.

Further experimentation is necessary before absolute statements can be made to substantiate the findings of this study, especially the effects of isokinetic training above 210°/s. In addition, it remains for further experimentation to substantiate or deny the effectiveness of the two different force-velocity training interactions used in this study. Other isokinetic stimuli may be as or more effective than the 30 and 60 P_o training stimuli.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

The purpose of this investigation was to evaluate the effects of isokinetic training on the force-velocity relationship and maximal power. In addition, a sub-purpose was to evaluate the effects of the isokinetic training on the maximal force and velocity exerted at peak maximal mechanical power output (MMPO) in individuals who possess different initial levels of maximal force at peak MMPO. Forty-two females participated and their ages ranged from 18 to 29 years.

All subjects were given a pretest on a Cybex II dynamometer which involved maximal voluntary contractions of the right forearm flexor muscles. The maximal torque exerted at an elbow angle of 90 degrees was recorded for five pre-set velocities of movement of 90, 150, 210, 270 and 300°/s. In addition, measurement of the maximal isometric force (P_o) at an elbow angle of 100, 120, 140 and 160° was recorded.

Force-velocity-power curves were plotted for each individual and the subjects were ranked based upon their ability to exert maximal force at peak MMPO. The subjects were then blocked into 21 individuals designated a high force group (Hi) and low force group (Lo) and were then randomly assigned to one of three treatment groups as follows:

I. A training group (30 P_o) who trained the right forearm at a maximal velocity of movement which corresponded to a maximal force production of 30% of their maximal isometric

force (P_o) as determined from individual force-velocity curves;

II. A training group (60 P_o) who trained the right forearm at a maximal velocity of movement which corresponded to a maximal force production of 60% of their maximal isometric force (P_o) as determined from individual force-velocity curves; and,

III. A control group (C) who was asked to maintain their same activity pattern during a five week training program.

Therefore, there were four training groups designated as Hi 30 P_o, Hi 60 P_o, Lo 30 P_o and Lo 60 P_o. The controls were designated as Hi C and Lo C. All groups contained 7 subjects.

A post-training test involving exactly the same measurements as in the pre-test was given to all treatment groups following the 5 week isokinetic training program. Composite pre and post-test F-V-P relationships were plotted and a 3-way analysis of variance with a repeated measure on time was used to analyze the dependent variables.

The results indicated that the Hi and Lo force group were significantly different at pre-test ($p < .05$) in their ability to exert maximal force at peak MMPO. Also, the two groups were significantly different ($p < .05$) at 90, 150 and 210°/s.

The pre-post composite F-V curves derived for the four training groups showed definite alterations in maximal force production. At the two slowest velocities measured (90 and 150°/s), the 60 P_o training stimulus was superior in both the Hi and Lo force training groups and the Lo force group showed a faster rate of improvement over time. At the middle velocity of 210°/s, both the Hi and Lo force training groups

responded to the 30 as well as the 60 P_o training stimulus, however, the Hi force groups had a better percentage increase (28.75) with the 30 P_o training and the Lo force group was slightly better (46.88) with the 60 P_o training. At the two highest velocities measured (270 and 300°/s.) both the Hi and Lo force groups responded more effectively to the 30 P_o training stimulus.

All four training groups increased in their ability to produce peak MMPO. Three of the four training groups (Hi 30 P_o, Hi 60 P_o, and Lo 30 P_o) increased their peak MMPO by displacing their F-V curves at the upper end and consequently produced their peak MMPO with lower maximal forces but at higher velocities. Only one group (Lo 60 P_o) increased their peak MMPO by displacing their F-V curve "all round" and therefore increasing both the maximal force and velocity at peak MMPO. The control groups (Hi C and Lo C) showed little alteration from pre to post-test.

Maximal isometric force (P_o) did not increase significantly ($p < .05$) from pre to post-test when taken as the greatest isometric force recorded at pre-test regardless of the angle of the forearm and re-measured at the same angle for the post-test. However, a significant main effect ($p < .05$) was found for the maximal isometric force exerted at an elbow angle of 100 degrees but not at 120, 140 or 160 degrees.

It seems apparent from the results obtained, that the 60 P_o training stimulus is more effective in displacing the F-V curve "all round" regardless of whether an individual is a Hi or Lo force generator and should be used when athletic event demands velocities of movement within the 90 to 210°/s range. If the event demands velocities in excess of 210°/s as for some limb movements, then the 30 P_o training stimulus

appears slightly more effective. If the objective is simply to increase the peak MMPO then a differential force-velocity training interaction is indicated for the Hi and Lo force generators (30 and 60 P_o, respectively).

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APPENDIX A

(Conversion of Angular Velocity to Linear Velocity)

Appendix A

Since the lever arm of the Cybex Dynamometer moves only at a pre-set maximal angular velocity (^{o}/sec.) the maximal linear velocity (m./sec.) can be represented by:

$$V = \frac{1.571}{(A/B)} \times (R/100) \qquad \text{III}$$

where:

V = the maximal linear velocity (m./sec.);

1.571 = the radian measure for 90 degs.;

A = the total angular displacement (90 degs.)

B = the maximal angular velocity (degs./sec.);

R = the radius of rotation (cm.); and

100 = a conversion to meters/sec.

Similarily, the maximal training linear velocity (m./sec.) obtained from individual force-velocity curves can be converted to an angular training velocity for the Cybex by:

$$W = \left[(V\text{x}100)/R\right] \times 57.3 \qquad \text{IV}$$

where:

W = the maximal angular velocity (degs/sec.);

V = the maximal linear velocity (m./sec.);

100 = a conversion to cm./sec.;

R = the radius of rotation (cm.); and

57.3 = the number of degrees in one radian.

APPENDIX B

(Conversion of Torque to Force)

Appendix B

The torque on the input shaft as measured by the Cybex Dynamometer is the product of force (lbs.) times the radius of rotation (ft.) measured perpendicular to the direction of force between the point of force application and the center of the input shaft. A simple equation can describe the torque as:

$$T = F \times R$$

where:

T = the maximal torque (ft.lbs.);

F = the maximal exerted force (lbs.); and

R = the radius of rotation

Thus:

The maximal torque (ft.lbs) can be converted to the maximal force (Kg.) by:

$$F = \left(\frac{T}{7.233}\right) / R$$

where:

F = the maximal exerted force (kg.);

T = the maximal torque (ft.lbs.);

7.233 = the number of ft.lbs. in 1 kilogram-meter; and

R = the radius of rotation (meters).

APPENDIX C

(Computer Program)

```
      ∇CURVE[⎕]∇
    ∇ CURVE
[1]   N←⍴X
[2]   LNX←⍟X
[3]   LNY←⍟Y
[4]   BBB←(+/X×LNY)-(1÷N)×(+/X)×(+/LNY)
[5]   BB←(+/X*2)-(1÷N)×(+/X)*2
[6]   B←BBB÷BB
[7]   A←*((+/LNY)÷N)-B×((+/X)÷N)
[8]   RRR←((+/X×LNY)-(1÷N)×(+/X)×(+/LNY))*2
[9]   RR←((+/X*2)-((+/X)*2)÷N)×(+/(LNY)*2)-((+/LNY)*2)÷N
[10]  '   '
[11]  YP←A×(2.71828)*(B)×XP
[12]  YYP←YP, 0 3
[13]  XXP←XP, 20 0
[14]  NN←20
[15]  P←XXP,YYP
[16]  T← 2 20 ⍴P
[17]  TT←⍉T
[18]  NN GRAPH TT
[19]  'SUBJECT IS     ';SUBJECT
[20]  'BEST FIT EXPONENTIAL CURVE FORCE/VELOCITY'
[21]  'THE EQUATION IS Y=AE*BX'
[22]  'WHERE A IS       ';A
[23]  'WHERE B IS    ';B
[24]  'AND E IS    ';2.71828
[25]  'THE COEFFICIENT OF DETERMINATION IS    ';RRR÷RR
[26]  POWER←XP×YP
[27]  P←XP,POWER
[28]  T← 2 18 ⍴P
[29]  TTT←⍉T
[30]  NNN←18
[31]  NNN GRAPH TTT
[32]  'POWER PLOT FROM BEST FIT FORCE/VELOCITY'
[33]  'SUBJECT IS       ';SUBJECT
[34]  XX←X, 20 0
[35]  YY←Y, 0 3
[36]  P←XX,YY
[37]  T1← 2 7 ⍴P
[38]  TT1←⍉T1
[39]  NN1←7
[40]  NN1 GRAPH TT1
[41]  'SUBJECT IS     ';SUBJECT
[42]  'PLOT OF ACTUAL VALUES ; VELOCITY/FORCE'
    ∇
```

APPENDIX D

(Training Program)

Appendix D

Training Program to be Followed for Five Weeks

Group	(Week)	(Session/Week)	x	(Repetitions)	=	(Total)
Hi 30% P_o	1	3		10	=	30
Hi 60% P_o	1	3		10	=	30
Lo 30% P_o	1	3		10	=	30
Lo 60% P_o	1	3		10	=	30
Hi 30% P_o	2	3		10	=	30
Hi 60% P_o	2	3		10	=	30
Lo 30% P_o	2	3		10	=	30
Lo 60% P_o	2	3		10	=	30
Hi 30% P_o	3	3		15	=	45
Hi 60% P_o	3	3		15	=	45
Lo 30% P_o	3	3		15	=	45
Lo 60% P_o	3	3		15	=	45
Hi 30% P_o	4	3		15	=	45
Hi 60% P_o	4	3		15	=	45
Lo 30% P_o	4	3		15	=	45
Lo 60% P_o	4	3		15	=	45
Hi 30% P_o	5	3		20	=	60
Hi 60% P_o	5	3		20	=	60
Lo 30% P_o	5	3		20	=	60
Lo 60% P_o	5	3		20	=	60

APPENDIX E

(Design)

Appendix E

COMMENTS AND DIAGRAMMATICAL DESCRIPTION OF SUBJECTS TO TO BLOCKS AND TREATMENTS AND THE OVERALL EXPERIMENTAL DESIGN

1. Subjects were ranked in order of their maximal exerted force at peak MMPO.

   1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28, 29,30,31,32,33,34,35,36,37,38,39,40,41,42

2. Subjects were then blocked according to their rank.

	Block 1	Block 2
	S_1 .... S_{21}	S_{22} .... S_{42}

3. Subjects from each block were then randomly assigned to one of three treatments.

(I)	(30 P_o)	Block 1	Block 2
(II)	(60 P_o)	Block 1	Block 2
(III)	(C)	Block 1	Block 2

4. Subjects were tested twice, once prior to training and once following the training program.

5. Thus, the design utilized was a 2 (blocks) x 3 (treatments) x 2 (time) factorial design (fixed model) with repeated measures on the last factor.

APPENDIX F

(Anthropometric Data)

Appendix F

ANTHROPOMETRIC DATA

Subject	Age(yrs.)	WT.(lbs.)	Length of Forearm (cm.)
1	20	127	29.0
2	20	130	30.5
3	19	142	31.0
4	18	127	30.5
5	21	113	27.5
6	18	123	29.0
7	19	135	29.0
8	19	140	32.0
9	19	136	30.0
10	22	138	27.5
11	19	135	30.5
12	21	120	31.0
13	25	134	31.0
14	20	155	31.0
15	20	122	32.0
16	19	132	29.5
17	25	123	31.0
18	23	128	30.5
19	27	135	31.0
20	19	126	31.0
21	21	118	28.0
22	19	132	33.0
23	19	130	32.0
24	19	164	32.0
25	23	105	28.0
26	22	137	32.0
27	21	120	28.0
28	22	115	30.0
29	29	134	30.0
30	20	135	31.0
31	20	138	31.0
32	20	138	32.0
33	23	120	29.5
34	25	126	30.0
35	25	118	28.5
36	22	117	28.0
37	24	119	30.0
38	22	130	29.0
39	26	136	32.0
40	23	142	33.0
41	21	115	31.0
42	18	142	29.5

Appendix F continued

Subject	Age (yrs)	Wt (lbs)	Length of Forearm (cm)
43	19	130	27.5
44	22	123	31.0
45	22	134	30.0
46	21	128	30.0
47	18	140	31.0
48	23	120	31.0
49	19	136	28.0
50	23	145	28.5
51	22	125	30.0
52	20	131	31.0
53	21	124	27.5
54	20	127	30.0
55	22	124	31.0
56	18	135	28.5
57	23	137	28.0
58	19	122	29.5
59	21	125	31.0
60	21	130	30.0

APPENDIX G

(Raw Scores From Pre and Post Training Test)

Appendix G - I

		MEAN FORCE (Kg.) (Two Trials)									
		at 90°/s.		at 150°/s.		at 210°/s		at 270°/s		at 300°/s	
Group	Sub.	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	1	11.66	11.27	9.75	10.61	6.96	8.34	3.67	6.20	2.55	5.89
	2	11.56	12.56	7.25	10.24	4.87	8.61	2.29	5.89	1.43	5.03
	3	8.14	10.03	5.40	7.20	2.79	5.13	0.67	3.28	0.00	2.79
(Hi 30P_o)	4	9.97	9.95	8.16	7.93	4.96	6.30	2.49	5.03	2.20	4.08
	5	10.66	9.85	7.94	8.07	4.50	5.83	1.71	4.15	1.63	3.77
	6	11.23	10.13	10.58	8.10	7.10	6.44	4.60	6.20	3.67	4.29
	7	11.58	11.80	9.96	10.49	7.03	8.58	4.08	6.67	3.38	5.84
	8	12.08	13.18	9.53	10.37	7.52	7.99	3.13	5.62	1.08	4.97
	9	8.64	9.38	5.84	6.80	4.01	6.36	1.38	2.60	0.23	1.73
	10	11.79	11.86	10.63	10.93	7.34	9.30	4.65	6.97	4.40	6.03
(Hi 60P_o)	11	11.33	12.40	9.93	10.43	6.80	7.84	4.08	5.69	3.29	5.21
	12	10.57	9.63	9.54	9.59	5.82	8.16	3.47	6.24	2.16	2.94
	13	9.59	10.64	6.91	9.48	4.91	7.36	2.23	5.40	0.89	4.46
	14	12.71	15.39	12.26	13.38	10.26	9.81	8.70	8.03	7.36	6.91
	15	9.18	8.27	6.46	6.80	4.43	4.97	1.75	1.47	0.91	1.06
	16	11.40	11.95	11.13	10.31	8.46	8.41	3.96	4.45	2.86	3.28
	17	10.70	11.17	9.12	9.19	6.42	6.27	3.12	2.92	2.59	2.01
(Hi C)	18	11.11	11.67	8.59	7.77	5.62	5.55	2.95	3.06	1.84	1.84
	19	9.81	10.03	7.14	7.58	4.24	4.13	1.46	2.01	0.98	1.11
	20	9.66	9.86	8.83	8.74	5.53	5.42	2.97	2.70	2.07	2.23
	21	12.52	12.22	12.17	11.12	10.57	10.25	7.88	6.76	7.18	6.69

Appendix G - II

Group	Sub.	Max P_o(Kg.) (Two Trials)		MMPO (Kgm./s.)		Force(Kg.) at Peak MMPO		Vel.(m./s.) at Peak MMPO	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
	1	10.97	10.73	6.65	9.07	7.00	5.89	0.950	1.540
	2	15.41	16.55	5.92	8.79	8.50	6.50	0.696	1.353
	3	11.81	10.48	4.24	5.78	7.00	6.25	0.605	0.924
(Hi $30P_o$)	4	11.47	12.31	5.71	7.04	7.00	5.00	0.816	1.408
	5	11.56	11.56	5.15	5.76	8.00	5.50	0.643	1.048
	6	13.83	13.35	7.06	7.36	7.50	4.50	0.941	1.635
	7	12.92	14.30	6.85	9.48	7.50	5.85	0.913	1.621
	8	15.55	14.90	7.41	8.68	9.50	5.00	0.780	1.736
	9	11.64	11.18	4.49	5.41	7.00	6.75	0.641	0.801
	10	13.32	14.30	6.98	9.30	7.00	6.04	0.997	1.540
(Hi $60P_o$)	11	12.47	13.60	7.08	8.62	7.50	6.50	0.944	1.326
	12	13.16	11.60	6.55	7.42	8.00	7.00	0.819	1.060
	13	12.04	15.16	5.34	7.94	7.50	5.50	0.712	1.443
	14	18.51	17.17	13.31	11.66	7.36	7.50	1.809	1.554
	15	13.18	12.96	5.15	5.07	7.00	7.00	0.736	0.724
	16	14.46	14.29	7.37	7.39	9.00	8.00	0.819	0.924
	17	14.05	13.38	6.61	6.62	7.50	8.50	0.881	0.779
(Hi C)	18	11.33	11.46	6.24	6.21	8.00	8.00	0.780	0.776
	19	15.16	14.94	5.36	5.51	7.50	8.00	0.715	0.689
	20	12.93	13.38	6.04	6.03	7.50	7.50	0.805	0.804
	21	16.05	15.31	11.17	9.92	7.20	6.70	1.550	1.480

Appendix G - III

		MEAN FORCE (Kg.) (Two Trials)									
		at 90°/s.		at 150°/s.		at 210°/s.		at 270°/s.		at 300°/s.	
Group	Sub.	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	1	6.35	9.22	5.09	6.66	4.29	5.15	2.75	3.71	2.68	3.16
	2	7.71	8.60	6.70	6.48	4.26	4.97	1.71	3.67	0.69	3.24
	3	10.97	10.17	9.12	7.86	6.80	6.05	4.26	5.08	3.59	4.43
(Lo $30P_o$)	4	8.69	8.91	6.94	7.09	4.94	6.49	3.46	3.90	3.09	2.99
	5	9.22	9.57	6.98	8.68	5.44	7.28	2.81	5.62	1.66	5.08
	6	6.02	10.20	3.23	8.25	1.15	5.10	0.00	3.95	0.00	3.26
	7	7.70	7.47	5.74	5.94	3.69	4.95	1.54	3.46	1.24	2.88
	8	8.30	11.06	7.44	9.59	6.91	7.37	4.63	4.95	3.96	4.61
	9	9.79	11.11	7.31	9.50	6.44	7.02	3.81	5.69	3.99	5.40
	10	10.03	15.39	7.78	13.38	6.13	10.70	4.71	8.03	3.57	6.69
(Lo $60P_o$)	11	9.40	10.95	7.63	9.51	5.51	7.45	4.17	5.88	3.91	5.10
	12	7.45	10.19	5.32	7.38	2.48	5.23	0.23	3.28	0.00	2.53
	13	5.71	7.60	1.77	6.11	0.46	3.85	0.00	2.63	0.00	1.96
	14	9.29	11.57	7.42	9.92	5.70	7.76	2.96	5.63	2.28	4.73
	15	8.12	8.15	7.28	6.67	5.51	5.81	3.28	3.46	2.25	3.09
	16	7.42	7.60	3.51	3.23	3.83	3.92	2.42	2.53	1.87	2.17
	17	7.63	7.77	5.72	6.32	4.10	4.12	2.46	2.74	1.93	1.91
(Lo C)	18	5.12	5.57	3.69	3.97	2.51	2.81	2.07	2.01	1.45	1.51
	19	10.80	10.79	9.01	8.55	6.49	6.68	4.61	4.57	3.56	3.96
	20	7.67	7.78	5.02	5.02	2.90	3.12	0.89	1.14	0.45	0.49
	21	11.04	10.85	10.29	10.12	7.94	7.71	5.11	4.99	4.15	3.75

Appendix G - IV

Group	Sub.	Max P_o(Kg.) (Two Trials)		MMPO (Kgm./s.)		Force(Kg.) at Peak MMPO		Vel.(m./s.) at Peak MMPO	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
	1	12.57	13.83	4.73	6.05	3.25	5.00	1.454	1.290
	2	10.35	9.83	4.78	5.74	6.50	4.50	0.735	1.276
	3	16.80	18.15	7.28	7.51	6.50	5.00	1.120	1.502
(Lo $30P_o$)	4	10.62	10.86	4.99	5.42	5.00	5.25	0.998	1.033
	5	13.39	14.69	5.56	9.06	6.50	5.09	0.855	1.780
	6	11.95	11.73	2.63	5.63	5.50	6.00	0.478	0.938
	7	10.02	10.60	4.14	5.00	5.50	3.75	0.753	1.334
	8	15.67	15.67	6.74	7.59	4.25	6.00	1.585	1.265
	9	14.94	14.05	6.46	8.61	5.00	5.50	1.292	1.565
	10	13.38	14.94	6.67	11.78	5.25	7.50	1.270	1.571
(Lo $60P_o$)	11	11.75	12.12	6.60	9.03	5.00	5.10	1.320	1.770
	12	12.23	14.06	3.75	5.53	6.00	6.50	0.625	0.851
	13	13.02	11.75	2.52	4.36	5.00	5.00	0.506	0.872
	14	14.55	16.37	5.19	7.71	6.00	6.00	0.865	1.285
	15	11.36	11.48	4.84	5.06	5.50	4.50	0.880	1.124
	16	7.47	7.56	4.06	4.16	4.50	4.75	0.902	0.876
	17	9.96	9.56	4.16	4.37	4.50	5.00	0.924	0.874
(Lo C)	18	11.45	10.80	3.10	3.32	3.00	3.25	1.033	1.022
	19	17.39	16.55	7.46	7.56	6.50	5.75	1.148	1.315
	20	12.31	12.80	4.00	4.05	6.50	6.00	0.615	0.675
	21	16.64	16.93	7.50	7.23	6.50	6.50	1.154	1.112

Appendix G - V

		MAXIMAL ISOMETRIC FORCE (Kg.) (Two Trials)							
		at 100°		at 120°		at 140°		at 160°	
Group	Sub.	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	1	10.97	10.73	10.97	10.97	10.49	10.73	8.34	8.94
	2	13.60	14.96	15.41	16.55	14.51	14.96	10.88	12.24
	3	11.80	10.48	11.60	9.14	10.48	7.47	6.47	4.79
(Hi $30P_o$)	4	11.47	12.31	10.79	10.92	8.79	9.86	6.82	7.12
	5	11.56	11.56	11.54	12.82	10.46	13.20	7.29	8.80
	6	12.63	12.42	13.83	13.35	12.39	11.68	8.82	8.77
	7	12.18	12.40	12.92	14.30	11.27	11.44	9.42	9.77
	8	15.55	14.90	14.26	14.04	11.67	12.75	10.37	10.37
	9	8.72	11.87	11.64	11.18	9.40	10.14	5.76	6.34
	10	13.32	14.30	12.82	13.07	12.07	13.32	10.56	12.32
(Hi $60P_o$)	11	12.47	13.60	10.20	10.43	8.61	9.52	7.48	7.71
	12	13.16	11.60	10.03	10.03	8.47	8.81	7.36	7.43
	13	12.04	15.16	11.15	11.60	10.70	11.15	8.03	8.47
	14	13.83	14.72	16.17	17.17	18.51	17.17	13.49	13.38
	15	12.75	12.96	13.18	12.96	12.10	11.67	10.37	10.37
	16	13.36	13.12	12.63	12.42	14.46	14.29	13.17	13.83
	17	13.38	13.38	13.38	13.38	11.37	11.15	8.47	7.80
(Hi C)	18	10.43	10.88	11.33	11.46	8.64	8.16	4.56	4.08
	19	14.49	14.49	15.16	14.94	12.49	12. 6	10.70	10.26
	20	11.60	12.71	12.93	13.38	10.70	9.81	9.37	8.36
	21	16.05	15.31	15.31	14.20	12.34	11.36	8.92	9.01

Appendix G - VI

		MAXIMAL ISOMETRIC FORCE (Kg.) (Two Trials)							
		at 100°		at 120°		at 140°		at 160°	
Group	Sub.	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	1	12.57	13.83	11.52	9.64	9.64	8.17	6.28	6.70
	2	10.35	9.83	9.81	9.14	8.10	7.34	6.70	5.44
	3	16.80	18.15	15.99	16.80	14.47	15.88	10.15	12.53
(Lo $30P_o$)	4	10.62	10.86	10.57	10.74	10.62	8.47	7.43	5.33
	5	11.69	11.67	13.39	14.69	13.18	14.26	11.88	12.31
	6	11.21	12.34	11.95	11.73	11.09	11.36	6.59	8.25
	7	10.02	10.60	9.45	9.54	9.06	7.67	7.00	6.38
	8	15.67	15.67	15.67	14.75	13.36	13.13	9.22	9.45
	9	14.94	14.05	12.93	13.38	13.83	13.38	10.93	11.37
	10	11.60	12.93	13.38	14.94	12.04	12.49	10.70	11.68
(Lo $60P_o$)	11	11.75	12.12	11.23	10.59	10.37	9.89	8.62	9.83
	12	12.23	14.06	12.23	13.12	10.78	10.31	8.20	9.84
	13	10.48	11.80	13.02	11.75	12.05	10.67	10.12	8.53
	14	14.55	16.37	13.34	14.55	14.55	14.55	9.22	10.91
	15	11.36	11.48	8.67	10.86	8.64	8.69	6.39	7.01
	16	7.47	7.56	7.19	7.10	6.34	6.73	4.84	5.05
	17	9.77	9.56	9.96	9.53	8.20	8.10	7.37	7.22
(Lo C)	18	11.15	9.40	11.45	10.80	9.38	8.79	5.64	5.79
	19	15.08	14.87	15.50	15.50	17.39	16.55	11.31	11.31
	20	12.31	12.76	11.68	12.04	10.44	11.37	7.16	8.81
	21	15.93	16.40	16.64	16.98	13.12	14.06	11.95	12.89

Appendix G-VII

		PRE-TEST MEAN FORCE (kg)(TWO TRIALS)				
		at 90°/s	at 150°/s	at 210°/s	at 270°/s	at 300°/s
Group	Sub	Pre	Pre	Pre	Pre	Pre
Hi 30 P_o	43	13.49	10.17	7.78	5.91	5.15
Hi 30 P_o	44	9.66	5.98	3.61	0.67	0.00
Hi 60 P_o	45	9.55	7.60	2.25	0.22	0.00
Hi 60 P_o	46	10.48	8.36	4.79	3.25	0.00
Lo 60 P_o	47	10.93	10.03	7.11	4.86	4.19
Lo 30 P_o	48	7.78	6.89	5.67	3.34	2.56
Lo 60 P_o	49	11.21	9.36	8.12	5.26	3.95
Lo 30 P_o	50	9.55	7.60	2.25	0.22	0.00
Hi 60 P_o	51	9.31	7.26	4.03	0.55	0.00
Lo 30 P_o	52	10.17	8.34	6.44	4.33	3.12
Hi 30 P_o	53	12.17	8.42	4.57	1.78	1.31
Lo 60 P_o	54	10.76	8.87	6.68	4.38	3.78
Hi C	55					
Hi C	56					
Hi C	57					
Lo C	58		(RESULTS OF #55 TO 60 DESTROYED)			
Lo C	59					
Lo C	60					

Appendix G-VII continued

		Max P_o (kg) (Two Trials)	MMPO (kgm/s)	Force (kg) at Peak MMPO	Vel (m/s) at Peak MMPO
Group	Sub	Pre	Pre	Pre	Pre
Hi 30 P_o	43	19.4	8.65	7.00	1.23
Hi 30 P_o	44	11.28	4.97	8.50	0.58
Hi 60 P_o	45	15.38	5.20	8.00	0.65
Hi 60 P_o	46	18.43	5.86	9.00	0.65
Lo 60 P_o	47	12.70	7.30	6.00	1.22
Lo 30 P_o	48	11.80	5.34	5.00	1.07
Lo 60 P_o	49	12.84	7.06	6.50	1.09
Lo 30 P_o	50	15.38	5.20	8.00	1.54
Hi 60 P_o	51	13.36	5.06	8.50	0.60
Lo 30 P_o	52	14.49	6.58	6.00	1.10
Hi 30 P_o	53	13.95	5.66	9.50	0.63
Lo 60 P_o	54	16.59	6.80	6.00	1.13
Hi C	55				
Hi C	56				
Hi C	57		(RESULTS OF #55 TO 60 DESTROYED)		
Lo C	58				
Lo C	59				
Lo C	60				

APPENDIX H

(Conversion of Individual Maximal Angular Velocities to meters/sec.)

Appendix H-I

Conversion of Individual Maximal Angular Velocity (^{o}/s) to meters/sec.

Group	Sub.	90^{o}/s to m/s	150^{o}/s to m/s	210^{o}/s to m/s	270^{o}/s to m/s	300^{o}/s to m/s
		Velocity Conversion (^{o}/s to m/s)				
Hi 30P_o	1	.46	.76	1.06	1.37	1.52
	2	.48	.80	1.12	1.44	1.60
	3	.49	.81	1.14	1.46	1.62
	4	.48	.80	1.12	1.44	1.60
	5	.43	.72	1.00	1.30	1.44
	6	.46	.76	1.06	1.37	1.52
	7	.46	.76	1.06	1.37	1.52
Hi 60P_o	8	.50	.84	1.17	1.51	1.68
	9	.47	.79	1.10	1.41	1.57
	10	.43	.72	1.00	1.30	1.44
	11	.48	.80	1.12	1.44	1.60
	12	.49	.81	1.14	1.46	1.62
	13	.49	.81	1.14	1.46	1.62
	14	.49	.81	1.14	1.46	1.62
Hi C	15	.50	.84	1.17	1.51	1.68
	16	.46	.77	1.08	1.39	1.54
	17	.49	.81	1.14	1.46	1.62
	18	.48	.80	1.12	1.44	1.60
	19	.49	.81	1.14	1.46	1.62
	20	.49	.81	1.14	1.46	1.62
	21	.44	.73	1.03	1.32	1.47
Lo 30P_o	22	.52	.86	1.21	1.55	1.73
	23	.50	.84	1.17	1.51	1.68
	24	.50	.84	1.17	1.51	1.68
	25	.44	.73	1.03	1.32	1.47
	26	.50	.84	1.17	1.51	1.68
	27	.44	.73	1.03	1.32	1.47
	28	.47	.79	1.10	1.41	1.57
Lo 60P_o	29	.47	.79	1.10	1.41	1.57
	30	.49	.81	1.14	1.46	1.62
	31	.49	.81	1.14	1.46	1.62
	32	.50	.84	1.17	1.51	1.68
	33	.46	.77	1.08	1.39	1.54
	34	.47	.79	1.10	1.41	1.57
	35	.45	.75	1.04	1.34	1.50

Appendix H-I (cont.)

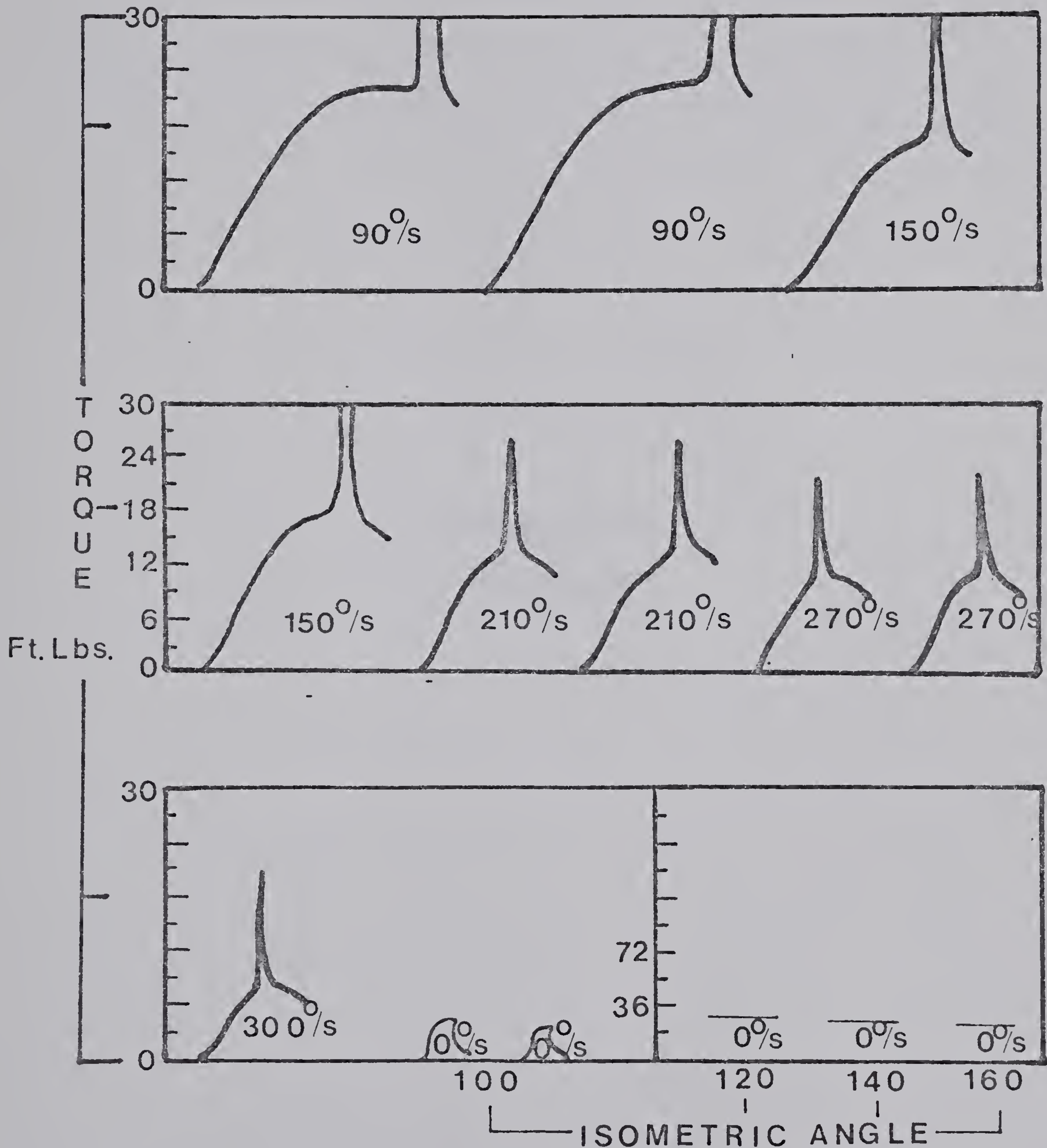
Conversion of Individual Maximal Angular Velocity (^{o}/s to meters/sec.

		Velocity Conversion (^{o}/s to m/s)				
Group	Sub.	90^{o}/s to m/s	150^{o}/s to m/s	210^{o}/s to m/s	270^{o}/s to m/s	300^{o}/s to m/s
	36	.44	.73	1.03	1.32	1.47
	37	.50	.84	1.17	1.51	1.68
	38	.46	.76	1.06	1.37	1.52
Lo C	39	.50	.84	1.17	1.51	1.68
	40	.52	.86	1.21	1.55	1.73
	41	.49	.81	1.14	1.46	1.62
	42	.46	.77	1.08	1.39	1.54

APPENDIX H-II

(A Retraced Example of Cybex Tracing for Subject #31)

Appendix H-II



APPENDIX H-III

RELIABILITY

Appendix H-III

RELIABILITY OF MAXIMAL ISOKINETIC TORQUE MEASUREMENTS
AT VARIOUS VELOCITIES AT AN ELBOW ANGLE OF 90 DEGREES

VELOCITY (degrees/sec)	CORRELATION COEFFICIENT (TEST-PRETEST) ON TWO TRIALS AT PRETEST
90	.90
150	.93
210	.95
270	.92
300	.97

APPENDIX I

(Statistical Analysis on Maximal Force Exerted at $90^{\circ}/s$)

APPENDIX I-I THREE-WAY ANALYSIS OF VARIANCE ON THE MAXIMAL FORCE EXERTED AT 90°/S

SUMMARY TABLE

SOURCE	SS	DF	MS	F	P
Bet. Sub	276.15	41			
A	84.36	1	84.36	17.94	0.001
B	19.85	2	9.92	2.11	0.14
AB	2.65	2	1.33	0.28	0.76
Sub W Group	169.29	36	4.70		
Within Sub	52.44	42			
C	13.31	1	13.31	20.80	0.001
AC	4.19	1	4.19	6.54	0.01
BC	9.23	2	4.61	7.21	0.01
C X Sub W Group	23.04	36			

I-II NEUMAN-KEULS ANALYSIS OF SIGNIFICANT AC INTERACTION OF MAXIMAL FORCE EXERTED AT 90°/S

	GROUP Hi	N=21/GROUP Lo
Post Mean Force	11.10	9.55
Pre Mean Force	10.76	8.31
Diff	0.34	1.24

*Significant interaction ($p < .05$) are not underscored by the same line.

The standard error of each interaction element is given by $[2(\text{ms within cell error})/n]^{1/2}$. Therefore, the standard error is $[2(.64)/21] = 0.25$.

The significant studentized range at the 5% level for tests of

ordered means 2 steps apart with 36 DF is 2.87.

Therefore, the range of the two interaction elements is judged significant if the range exceeded the critical value of (.25)(2.87)=0.71.

I-III ONE-WAY ANALYSIS OF VARIANCE ON THE MAXIMAL FORCE EXERTED AT 90°/S AT PRE AND POST-TEST FOR THE HI VS LO FORCE GROUP

PRE-TEST (HI VS LO)					POST-TEST (HI VS LO)				
S	SS	DF	MS	F	S	SS	DF	MS	F
B	63.04	1	63.04	23.61*	B	25.48	1	25.48	9.54*
W	88.95	40	2.67		W	137.55	40	2.67	
T	151.99	41			T	163.03	41		

Critical Value = 4.08 * = Sig. at ($p < .05$)

I-IV NEUMAN-KEULS COMPARISON OF SIGNIFICANT BC INTERACTION FOR MAXIMAL FORCE EXERTED AT 90°/S

	GROUPS C	N=14 / GROUP 30	60
Post Mean Force	9.55	9.98	11.45
Pre Mean Force	9.45	9.38	10.13
Diff	0.10	0.60	1.32

*Significant interactions ($p < .05$) are not underscored by the same line.

The standard error of each interaction element is given by: $[2(\text{ms within cell error})n]^{1/2}$. Therefore, the standard error is $[2(.64)/14]^{1/2} = .30$.

The significant studentized ranges at the 5% level for tests of ordered means 2 and 3 steps apart with 36 DF are 2.87 and 3.46, respectively.

Therefore, the range of all three interaction elements is judged significant if the range exceeded the critical value of (.30)(3.46) = 1.04.

Similarly, the range of two adjacent interaction elements is judged significant if the range exceeded (.30)(2.87) = 0.86

I-V ONE-WAY ANALYSIS OF VARIANCE PERFORMED ON THE POST-TEST MAXIMAL FORCE EXERTED AT 90°/S BETWEEN THE 30 P_o, 60 P_o, AND CONTROL GROUP (N=14/GROUP)

S	SS	DF	MS	F
B	27.84	2	13.92	5.21*
W	135.44	39	2.67	
T	163.28	41		

Critical Value = 3.24 * = Sig at ($p < .05$)

I-VI NEUMAN-KEULS COMPARISON OF ORDERED POST-TEST MEANS BETWEEN THE 30 P_o, 60 P_o AND CONTROL GROUP (N=14/GROUP) AT 90°/S

		ORDERED MEANS		
		9.55	9.98	11.45
		C	30	60
TABLE OF OBSERVED Q VALUES	C		1.00	4.42*
	30			3.42*
	60			

* = Sig. at ($p < .05$)

Observed Q values obtained from the difference between two means

divided by the standard error of the mean give by: $[(\text{ms pooled cell error})/n]^{1/2}$. Therefore, the standard error is $[2.67/14]^{1/2} = .44$.

Critical values of Q for ordered mean 3 and 2 steps apart with 39 DF are 3.45 and 2.86, respectively. The difference between two means is judged significant if the observed Q value is equal to or greater than the appropriate critical Q value.

APPENDIX J

(Statistical Analysis of Maximal Force Exerted at 150°/s)

APPENDIX J-I THREE-WAY ANALYSIS OF VARIANCE ON THE MAXIMAL FORCE EXERTED AT 150°/S

SUMMARY TABLE

SOURCE	SS	DF	MS	F	P
Bet. Sub.	374.75	41			
A	94.36	1	94.36	13.32	0.001
B	22.74	2	11.37	1.60	0.22
AB	2.56	2	1.28	0.18	0.84
Sub. W Group	255.09	36	7.09		
Within Sub.	69.49	42			
C	14.79	1	14.79	17.14	0.001
AC	4.40	1	4.40	5.10	0.03
BC	15.73	2	7.86	9.11	0.001
ABC	3.50	2	1.75	2.03	0.15
C X Sub W Group	31.06	36	0.86		

J-II NEUMAN-KEULS ANALYSIS OF SIGNIFICANT AC INTERACTION OF MAXIMAL FORCE EXERTED AT 150°/S

	GROUPS HI	N=21/GROUP LO
Post Mean Force	9.29	7.63
Pre Mean Force	8.91	6.33
Diff	0.38	1.30

*Significant interactions ($p < .05$) are not underscored by the same line.

The standard error of each interaction element is given by: $[2(\text{ms within cell error})/n]^{1/2}$. Therefore, the standard error is

$[2(.86)/21]^{1/2} = 0.35.$

The significant studentized range at the 5% level for tests of ordered means 2 steps apart with 36 DF is 2.87. Therefore, the range of the two interaction elements is judged significant if the range exceeded the critical value of (.35)(2.87) = 0.92.

J-III ONE-WAY ANALYSIS OF VARIANCE ON THE MAXIMAL FORCE EXERTED AT 150 °/S AT PRE AND POST-TEST FOR THE HI VS LO FORCE GROUP (N=21/GROUP)

PRE-TEST (HI VS LO)					POST-TEST (HI VS LO)				
S	SS	DF	MS	F	S	SS	DF	MS	F
B	69.75	1	69.75	17.92*	B	28.99	1	28.99	7.28*
W	165.24	40	3.98		W	165.16	40	3.98	
T	234.99	41			T	194.15	41		

Critical value = 4.08 * = Sig. at ($p < .05$)

J-IV NEUMAN-KEULS ANALYSIS OF SIGNIFICANT BC INTERACTION FOR MAXIMAL FORCE EXERTED AT 150°/S

	GROUPS C	N=14 / GROUP 30	60
Post Mean Force	7.53	8.31	9.74
Pre Mean Force	7.71	7.35	7.80
Diff	-.18	0.76	1.94

*Significant interactions ($p < .05$) are not underscored by the same line.

The standard error of each interaction element is given by: $[2(\text{ms within cell error})/n]^{1/2}$. Therefore, the standard score is: $[2(.86)/14]^{1/2} = .35$

The significant studentized ranges at the 5% level for tests of ordered means 3 and 2 steps apart with 36 DF are 3.46 and 2.87, respectively.

Therefore, the range of all three interaction elements is judged significant if the range exceeded the critical value of (.35)(3.46) = 1.21.

Similarly, the range of two adjacent interaction elements is judged significant if the range exceeded (.35)(2.87) = 1.00.

J-V ONE-WAY ANALYSIS OF VARIANCE PERFORMED ON THE POST-TEST MAXIMAL FORCE EXERTED AT 150°/S BETWEEN THE 30 P_o, 60 P_o AND CONTROL GROUP (N=14/GROUP)

S	SS	DF	MS	F
B	36.80	2	18.40	4.62*
W	157.51	39	3.98	
T	194.31	41		

Critical Value = 3.24 * = Sig. at ($p < .05$)

J-VI NEUMAN-KEULS COMPARISON OF ORDERED POST-TEST MEANS BETWEEN THE 30 P_o, 60 P_o AND CONTROL GROUP (N=14/GROUP) AT 300°/S

		ORDERED MEANS		
		7.53	8.11	9.74
		C	30	60
TABLE OF OBSERVED Q VALUES	C		1.09	4.17*
	30			3.08*
	60			

* = Sig. at ($p < .05$)

Observed Q values obtained from the difference between two means divided by the standard error of the mean given by:

$[(\text{ms pooled cell error}/n)]^{1/2}$.

Therefore, the standard error is $[3.98/14]^{1/2} = .53$.

Critical values of Q for ordered means 3 and 2 steps apart with 39 DF are 3.45 and 2.86 respectively. The difference between two means is judged significant if the observed Q value is equal to or greater than the appropriate critical Q value.

APPENDIX K

(Statistical Analysis of Maximal Force Exerted at 210°/s)

APPENDIX K-I THREE WAY ANALYSIS OF VARIANCE ON THE MAXIMAL FORCE EXERTED AT 210°/S

SUMMARY TABLE

SOURCE	SS	DF	MS	F	P
Bet. Sub.	291.98	41			
A	43.10	1	43.10	6.78	0.01
B	19.52	2	9.76	1.54	0.23
AB	0.64	2	0.32	0.05	0.95
Sub W Group	228.72	36	6.35		
Within Sub	62.10	42			
C	26.26	1	26.26	43.12	0.001
AC	0.32	1	0.32	0.52	0.48
BC	12.65	2	6.32	10.38	0.001
ABC	0.94	2	0.47	0.77	0.47
C X Sub W Group	21.93	36	0.61		

K-II ONE-WAY ANALYSIS OF VARIANCE ON THE MAXIMAL FORCE EXERTED AT 210°/S AT PRE AND POST-TEST FOR THE HI VS LO FORCE GROUP (N=21/GROUP)

	PRE-TEST (HI VS LO)					POST-TEST (HI VS LO)			
S	SS	DF	MS	F	S	SS	DF	MS	F
B	25.39	1	25.39	7.30*	B	18.01	1	18.01	5.18*
W	155.24	40	3.48		W	128.87	41	3.48	
T	180.63	41			T	146.88			

Critical Value = 4.08 * = Sig at ($p < .05$)

K-III NEUMAN-KEULS ANALYSIS OF SIGNIFICANT BC INTERACTION FOR MAXIMAL FORCE EXERTED AT 210°/S

	GROUPS C	N=14 / GROUP 30	60
Post Mean Force	5.66	6.37	7.59
Pre Mean Force	5.61	4.92	5.74
Diff	0.05	1.45	1.85

*Significant interactions ($p < .05$) are not underscored by the same line.

The standard error of each interaction element is given by: $[2(\text{ms within cell error})/n]^{1/2}$.

Therefore, the standard error is $[2(.61)/14]^{1/2} = .30$.

The significant studentized ranges at the 5% level for tests of ordered means 3 and 2 steps apart with 36 DF are 3.46 and 2.87, respectively.

Therefore, the range of all three interaction elements is judged significant if the range exceeded the critical value of (.30)(3.46) = 1.04.

Similarly, the range of two adjacent interaction elements is judged significant if the range exceeded (.30)(2.87) = 0.86.

K-IV ONE-WAY ANALYSIS OF VARIANCE PERFORMED ON THE POST-TEST MAXIMAL FORCE EXERTED AT 210°/S BETWEEN THE 30 P_o, 60 P_o AND CONTROL GROUP (N=14/GROUP)

S	SS	DF	MS	F
B	26.67	2	13.34	3.83*
W	120.39	39	3.48	
T	147.06			

Critical Value = 3.24 * = Sig. at ($p < .05$)

K-V NEUMAN-KEULS COMPARISON OF ORDERED POST-TEST MEANS BETWEEN THE 30 P_o, 60 P_o AND CONTROL GROUP (N=14/GROUP) AT 210°/S

		ORDERED MEANS		
		5.66	6.37	7.59
		C	30	60
TABLE OF OBSERVED VALUES	C		1.42	3.86*
	30			2.44
	60			

* = Sig. at ($p < .05$)

Observed Q values obtained from the difference between two means divided by the standard error of the mean given by: $[(\text{ms pooled cell error}/n]^{1/2}$.

Therefore, the standard error is $[3.48/14]^{1/2} = .50$.

Critical values of Q for ordered means 3 and 2 steps apart with 39 DF are 3.45 and 2.86 respectively. The difference between two means is judged significant if the observed Q value is equal to or greater than the appropriate critical Q value.

APPENDIX L

(Statistical Analysis of Maximal Force Exerted at 270°/s)

APPENDIX L-I THREE-WAY ANALYSIS OF VARIANCE ON THE MAXIMAL FORCE EXERTED AT 270°/S

SUMMARY TABLE

SOURCE	SS	DF	MS	F	P
Bet. Sub	220.59	41			
A	9.32	1	9.32	1.78	0.19
B	22.17	2	11.09	2.12	0.13
AB	0.84	2	0.42	0.08	0.92
Sub W Group	188.26	36	5.23		
Within Sub	78.61	42			
C	41.92	1	41.92	103.41	0.001
AC	0.02	1	0.02	0.04	0.83
BC	20.88	2	10.44	25.76	0.001
ABC	1.19	2	0.60	1.47	0.24
C X Sub W Group	14.59	36	0.41		

L-II NEUMAN-KEULS COMPARISON OF SIGNIFICANT BC INTERACTION FOR MAXIMAL FORCE EXERTED AT 270°/S

	GROUPS C	N=14 / GROUP 60	30
Post Mean Force	3.20	5.47	4.78
Pre Mean Force	3.21	3.44	2.58
Diff	-.01	2.20	2.03

*Significant interactions ($p < .05$) are not underscored by the same line.

The standard error of each interaction element is given by: $[2(\text{ms within cell error})/n]^{1/2}$.

Therefore, the standard error is: $[2(.41)/14]^{1/2} = .24$.

The significant studentized ranges at the 5% level for tests of ordered means 2 and 3 steps apart with 36 DF are 2.87 and 3.46, respectively.

Therefore, the range of all three interaction elements is judged significant if the range exceeded (.24)(3.46) = 0.83.

Similarly, the range of two adjacent interaction elements is judged significant if the range exceeded (.24)(2.87) = 0.69.

L-III ONE-WAY ANALYSIS OF VARIANCE PERFORMED ON THE POST-TEST MAXIMAL FORCE EXERTED AT 270°/S BETWEEN THE 30 P_o, 60 P_o AND CONTROL GROUP (N=14/GROUP)

S	SS	DF	MS	F
B	37.95	2	18.97	6.75*
W	86.02	39	2.81	
T	123.97			

Critical Value = 3.24 * = Sig. at ($p < .05$)

L-IV NEUMAN-KEULS COMPARISON OF ORDERED POST-TEST MEANS BETWEEN THE 30 P_o, 60 P_o AND CONTROL GROUP (N=14/GROUP) AT 270°/S

		ORDERED MEANS 3.20 C	4.78 30	5.47 60
TABLE OF OBSERVED Q VALUES	C		3.51*	5.04*
	30			1.53
	60			

* = Sig. at ($p < .05$)

Observed Q values obtained from the difference between two means divided by the standard error of the mean given by:

$[(\text{ms pooled cell error})/n]^{1/2}$

Therefore, the standard error is $[2.81/14]^{1/2} = .45$.

Critical values of Q for ordered means 3 and 2 steps apart with 39 DF are 3.45 and 2.86, respectively. The difference between two means is judged significant if the observed Q value is equal to or greater than the appropriate critical Q value.

APPENDIX M

(Statistical Analysis of Maximal Force Exerted at 300°/s)

APPENDIX M-I THREE-WAY ANALYSIS OF VARIANCE ON THE MAXIMAL FORCE EXERTED AT 300 °/S

SUMMARY TABLE

SOURCE	SS	DF	MS	F	P
Bet. Sub	195.47	41			
A	2.90	1	2.90	0.60	0.44
B	17.38	2	8.69	1.79	0.18
AB	0.63	2	0.31	0.06	0.94
Sub W. Group	174.56	36	4.85		
Within Sub	73.96	42			
C	37.44	1	37.44	71.88	0.001
AC	0.01	1	0.01	0.18	0.67
BC	16.89	2	8.44	16.21	0.001
ABC	0.79	2	0.39	0.76	0.48
C X Sub W Group	18.75	36	0.52		

M-II NEUMAN-KEULS ANALYSIS OF SIGNIFICANT BC INTERACTION FOR MAXIMAL FORCE EXERTED AT 300°/S

	GROUPS C	N=14 / GROUP 60	30
Post Mean Force	2.51	4.52	4.06
Pre Mean Force	2.43	2.65	1.99
Diff	.08	1.87	2.07

*Significant interactions ($p < .05$) are not underscored by the same line.

The standard error of each interaction element is given by: $[2(\text{ms within cell error})/n]^{1/2}$.

Therefore, the standard error is $[2(.52)/14]^{1/2} = .27$.

The significant studentized ranges at the 5% level for tests of ordered means 2 and 3 steps apart with 36 DF are 2.87 and 3.46, respectively.

Therefore, the range of all three interaction elements is judged significant if the range exceeded (.27)(3.46) = 0.93.

Similarly, the range of two adjacent interaction elements is judged significant if the range exceeded (.27)(2.87) = 0.77.

M-III ONE-WAY ANALYSIS OF VARIANCE PERFORMED ON THE POST-TEST MAXIMAL FORCE EXERTED AT 300 °/S BETWEEN THE 30 P_o, 60 P_o AND CONTROL GROUP (N=14/GROUP)

S	SS	DF	MS	F
B	31.05	2	15.53	5.77*
W	82.82	39	2.69	
T	113.87	41		

Critical Value = 3.24 *=Sig. at ($p < .05$)

M-IV NEUMAN-KEULS COMPARISON OF ORDERED POST-TEST MEANS BETWEEN THE 30 P_o, 60 P_o AND CONTROL GROUP (N=14/GROUP) AT 300°/S

		ORDERED MEANS		
		2.51	4.06	4.52
		C	30	60
TABLE OF OBSERVED Q VALUES	C		3.52*	4.57*
	30			1.05
	60			

* = Sig. at ($p < .05$)

Observed Q values obtained from the difference between two means divided by the standard error of the mean given by:

[(ms pooled cell error/n].

Therefore the standard error is $[2.69/14]^{1/2} = .44$.

Critical values of Q for ordered means 3 and 2 steps apart with 39 DF are 3.45 and 2.86, respectively. The difference between two means is judged significant if the observed Q value is equal to or greater than the appropriate critical Q value.

APPENDIX N

(Statistical Analysis on MMPO)

APPENDIX N-I THREE-WAY ANALYSIS OF VARIANCE PERFORMED ON PEAK MAXIMAL MECHANICAL POWER OUTPUT

SUMMARY TABLE

SOURCE	SS	DF	MS	F	P
Bet. Sub	291.03	41			
A	39.79	1	39.79	6.43	0.02
B	27.43	2	13.72	2.22	0.12
AB	1.14	2	0.57	0.09	0.91
Sub W Group	222.68	36	6.19		
Within Sub	61.54	42			
C	25.18	1	25.18	45.87	0.001
AC	1.02	1	1.02	1.85	0.18
BC	13.64	2	6.82	12.43	0.001
ABC	1.94	2	0.97	1.77	0.18
C X Sub W Group	19.76	36	0.55		

N-II NEUMAN-KEULS ANALYSIS OF SIGNIFICANT BC INTERACTION FOR PEAK MMPO

	GROUP C	N=14/GROUP 60	30
Post MMPO	5.90	8.12	6.98
Pre MMPO	5.94	6.37	5.19
Diff	-.04	1.75	1.79

*Significant interactions ($p < .05$) are not underscored by the same line.

The standard error of each interaction element is given by: $[2(\text{ms within cell error})/n]^{1/2}$.

Therefore, the standard error is $[2(.55)/14]^{1/2} = 0.28$.

The significant studentized ranges at the 5% level of ordered means 2 and 3 steps apart with 36 DF are 2.87 and 3.46, respectively.

Therefore, the range of all three interaction elements is judged significant if the range exceeded the critical value of (0.28)(3.46) = 0.97.

Similarly, the range of two adjacent interaction elements is judged significant if the range exceeded (0.28)(2.87) = 0.80.

N-III ONE-WAY ANALYSIS OF VARIANCE PERFORMED ON THE POST-TEST MMPO BETWEEN THE 30 P_o, 60 P_o AND CONTROL GROUP (N=14/GROUP)

S	SS	DF	MS	F
B	34.64	2	17.32	5.14*
W	130.80	39	3.37	
T	165.44	41		

Critical Value = 3.24 * = Sig. at ($p < .05$)

N-IV NEUMAN-KEULS COMPARISON OF ORDERED POST-TEST MEANS BETWEEN THE 30 P_o, 60 P_o AND CONTROL GROUP (N=14/GROUP) FOR MMPO

TABLE OF OBSERVED Q VALUES	ORDERED MEANS	5.90 C	6.98 30	8.12 60
	C		2.20	4.53*
	30			2.33
	60			

* = Sig. at ($p < .05$)

Observed Q values obtained from the difference between two means divided by the standard error of the mean given by: $[(\text{ms pooled cell error})/n]^{1/2}$.

Therefore, the standard error is $[3.37/14]^{1/2} = .49$.

Critical values of Q for ordered means 3 and 2 steps apart with 39 DF are 3.45 and 2.86, respectively. The difference between two means is judged significant if the observed Q value is equal to or greater than the appropriate critical Q value.

APPENDIX O

(Statistical Analysis of Maximal Force Exerted at Peak MMPO)

APPENDIX O-I THREE-WAY ANALYSIS OF VARIANCE PERFORMED ON THE MAXIMAL FORCE EXERTED AT PEAK MMPO

SUMMARY TABLE

SOURCE	SS	DF	MS	F	P
Bet. Sub	109.33	41			
A	64.05	1	64.05	65.04	0.001
B	4.22	2	2.11	2.14	0.13
AB	5.61	2	2.80	2.85	0.07
Sub W Group	35.45	36	0.98		
Within Sub	41.51	42			
C	6.24	1	6.24	11.41	0.01
AC	5.90	1	5.90	10.80	0.01
BC	5.06	2	2.53	4.63	0.02
ABC	4.64	2	2.32	4.24	0.02
C X Sub W Group	19.68	36	0.55		

O-II NEUMAN-KEULS ANALYSIS OF SIGNIFICANT AC INTERACTION FOR MAXIMAL FORCE EXERTED AT PEAK MMPO

	GROUP LO	N=21/GROUP HI
Pre Mean Force	5.35	7.62
Post Mean Force	5.33	6.55
Diff	0.02	1.07

*Significant interactions ($p < .05$) are not underscored by the same line.

The standard error of each interaction element is given by: $[2(\text{ms within cell error})/n]^{1/2}$.

Therefore, the standard error is $[2(.55)/21]^{1/2} = 0.23$.

The significant studentized range at the 5% level for tests of ordered means 2 steps apart with 36 DF is 2.87.

Therefore, the range of the two interaction elements is judged significant if the range exceeded the critical value of (.23)(2.87)=.66.

O-III ONE-WAY ANOVAS PERFORMED ON THE MAXIMAL FORCE EXERTED AT PEAK MMPO AT PRE AND POST-TEST FOR THE HI VS LO FORCE GROUP (N=21/GROUP)

PRE (HI VS LO)					POST (HI VS LO)				
S	SS	DF	MS	F	S	SS	MF	MS	F
B	54.42	1	54.42	70.68*	B	15.53	1	15.53	20.17*
W	31.22	40	0.77		W	43.39	40	0.77	
T	85.64	41			T	58.92	41		

Critical Value = 4.08 * = Sig. at ($p < .05$)

O-IV NEUMAN-KEULS ANALYSIS OF SIGNIFICANT BC INTERACTION FOR MAXIMAL FORCE EXERTED AT PEAK MMPO

	GROUP C	N=14 / 60P_o	GROUP 30P_o
Pre Mean Force	6.48	6.45	6.52
Post Mean Force	6.39	6.14	5.29
Diff	0.09	0.31	1.23

*Significant interactions ($p < .05$) are not underscored by the same line.

The standard error of each interaction element is given by: $[2(\text{ms within cell error})/n]^{1/2}$.

Therefore, the standard error is $[2(.55)/14]^{1/2} = 0.28$.

The significant studentized ranges at the 5% level for tests of ordered means 2 and 3 steps apart with 36 DF are 2.87 and 3.46, respectively.

Therefore, the range of all three interaction elements is judged significant if the range exceeded the critical value of (.28)(3.46)=.97.

Similarly, the range of two adjacent interaction elements is judged significant if the range exceeded (.28)(2.87) = .80.

O-V ONE-WAY ANALYSIS OF VARIANCE PERFORMED ON THE POST-TEST MAXIMAL FORCE EXERTED AT PEAK MMPO BETWEEN THE 30 P_o, 60 P_o AND CONTROL GROUP (N=14/GROUP)

S	SS	DF	MS	F
B	9.25	2	4.63	6.01*
W	49.70	39	.77	
T	58.95	41		

Critical Value = 3.24 * = Sig. at ($p < .05$)

O-VI NEUMAN-KEULS COMPARISON OF ORDERED POST-TEST MEANS BETWEEN THE 30 P_o, 60 P_o AND CONTROL GROUP (N=14/GROUP) FOR THE MAXIMAL FORCE EXERTED AT PEAK MMPO

		ORDERED MEANS		
		5.29	6.14	6.39
		30	60	C
TABLE OF OBSERVED Q VALUES	30		3.70*	4.78*
	60			1.09
	C			

* = Sig. at ($p < .05$)

Observed Q values obtained from the difference between two means divided by the standard error of the mean given by:

$[(\text{ms pooled cell error})/n]^{1/2}$.

Therefore, the standard error is $[1.27/14]^{1/2} = .23$.

Critical values of Q for ordered means 3 and 2 steps apart with 39 DF are 3.45 and 2.86, respectively. The difference between two means is judged significant if the observed Q value is equal to or greater than the appropriate critical Q value.

APPENDIX P

(Statistical Analysis of Maximal Velocity at Peak MMPO)

APPENDIX P-I THREE-WAY ANALYSIS OF VARIANCE ON THE MAXIMAL VELOCITY AT PEAK MMPO

SUMMARY TABLE

SOURCE	SS	DF	MS	F	P
Bet. Sub	6.09	41			
A	0.05	1	0.05	0.36	0.55
B	0.83	2	0.42	3.00	0.07
AB	0.01	2	0.005	0.04	0.96
Sub W Group	5.19	36	0.14		
Within Sub	3.62	42			
C	1.56	1	1.56	52.00	0.001
AC	0.04	1	0.04	1.33	0.29
BC	0.78	2	0.39	13.00	0.001
ABC	0.06	2	0.03	1.00	0.41
C X Sub W Group	1.19	36	0.03		

P-II NEUMAN-KEULS ANALYSIS OF SIGNIFICANT BC INTERACTION FOR MAXIMAL VELOCITY AT PEAK MMPO

	GROUP	N = 14 /	GROUP
	C	60	30
Post Mean Velocity	0.941	1.331	1.334
Pre Mean Velocity	0.925	1.012	0.854
Diff	0.02	0.32	0.48

*Significant interactions ($p < .05$) are not underscored by the same line.

The standard error of each interaction element is given by: $[2(\text{ms within cell error})/n]^{1/2}$.

Therefore, the standard error is $[2(.03)/14]^{1/2} = .07$.

The significant studentized range at the 5% level for tests of ordered means 2 and 3 steps apart with 36 DF are 2.87 and 3.46, respectively.

Therefore, the range of all three interaction elements is judged significant if the range exceeded the critical value of (.07)(3.46) = 0.24.

Similarly, the range of two adjacent interaction elements is judged significant if the range exceeded (.07)(2.87) = 0.20.

P-III ONE-WAY ANALYSIS OF VARIANCE PERFORMED ON THE POST-TEST MAXIMAL VELOCITY AT PEAK MMPO BETWEEN THE 30 P_o, 60 P_o AND CONTROL GROUP (N=14/GROUP)

S	SS	DF	MS	F
B	1.43	2	0.72	9.00*
W	3.09	39	0.08	
T	4.52	41		

Critical Value = 3.24 * = Sig. at ($p < .05$)

P-IV NEUMAN-KEULS COMPARISON OF ORDERED POST-TEST MEANS BETWEEN THE 30 P_o, 60 P_o AND CONTROL GROUP (N=14/GROUP) FOR THE MAXIMAL VELOCITY AT PEAK MMPO

		ORDERED MEANS		
		0.941	1.331	1.334
		C	60	30
TABLE OF OBSERVED Q VALUES	C		4.88*	4.91*
	60			0.04
	30			

* = Sig. at ($p < .05$)

Observed Q values obtained from the difference between two means divided by the standard error of the mean given by: $[(\text{ms pooled cell error})/n]^{1/2}$.

Therefore, the standard error is $[.08/14]^{1/2} = .08$.

Critical values of Q for ordered means 3 and 2 steps apart with 39 DF are 3.45 and 2.86, respectively. The difference between two means is judged significant if the observed Q value is equal to or greater than the appropriate critical Q value.

APPENDIX Q

(Statistical Analysis of Maximal Isometric Force P_o)

Q-I THREE-WAY ANALYSIS OF VARIANCE ON THE MAXIMAL ISOMETRIC FORCE (P_o)

SUMMARY TABLE

SOURCE	SS	DF	MS	F	P
Bet. Sub	414.05	41			
A	6.04	1	6.04	0.58	0.45
B	24.52	2	12.26	1.18	0.32
AB	9.20	2	4.60	0.44	0.65
Sub W Group	374.29	36	10.40		
Within Sub	21.56	42			
C	0.70	1	0.69	1.31	0.26
AC	0.35	1	0.35	0.65	0.42
BC	1.28	2	0.64	1.20	0.31
ABC	0.08	2	0.04	0.07	0.93
C X Sub W Group	19.16	36	0.53		

APPENDIX R

(Statistical Analysis on the Maximal Isometric Force (P_o) at an Elbow Angle of 100, 120, 140 and 160 Degrees)

R-I THREE-WAY ANALYSIS OF VARIANCE ON THE MAXIMAL ISOMETRIC FORCE (P_o) AT AN ELBOW ANGLE OF 100°

SUMMARY TABLE

SOURCE	SS	DF	MS	F	P
Bet. Sub	339.71	41			
A	2.80	1	2.80	0.33	0.57
B	21.47	2	10.74	1.27	0.29
AB	11.61	2	5.80	0.69	0.51
Sub W Group	303.83	36	8.44		
Within Sub	26.00	42			
C	3.54	1	3.54	6.79	0.01
AC	0.004	1	0.004	0.01	0.93
BC	3.13	2	1.57	3.01	0.06
ABC	0.57	2	0.28	0.54	0.59
C X Sub W Group	18.76	36	0.52		

R-II THREE-WAY ANALYSIS OF VARIANCE ON THE MAXIMAL ISOMETRIC FORCE (P_o) AT AN ELBOW ANGLE OF 120°

SUMMARY TABLE

SOURCE	SS	DF	MS	F	P
Bet. Sub	410.41	41			
A	5.48	1	5.48	0.52	0.47
B	6.64	2	3.32	0.32	0.73
AB	20.81	2	10.40	0.99	0.38
Sub W Group	377.47	36	10.49		
Within Sub	17.07	42			
C	0.12	1	0.12	0.26	0.61
AC	0.03	1	0.03	0.07	0.80
BC	0.13	2	0.06	0.14	0.87
ABC	0.29	2	0.14	0.31	0.73
C X Sub W Group	16.50	36	0.46		

R-III THREE-WAY ANALYSIS OF VARIANCE ON THE MAXIMAL ISOMETRIC FORCE (P_o) AT AN ELBOW ANGLE OF 140°

SUMMARY TABLE

SOURCE	SS	DF	MS	F	P
Bet. Sub	520.05	41			
A	1.68	1	1.68	0.12	0.73
B	16.54	2	8.27	0.61	0.55
AB	10.16	2	5.08	0.37	0.69
Sub W Group	491.68	36	13.66		
Within Sub	22.48	42			
C	0.14	1	0.14	0.26	0.62
AC	0.34	1	0.34	0.61	0.44
BC	0.32	2	0.16	0.30	0.75
ABC	1.94	2	0.97	1.77	0.19
C X Sub W Group	19.74	36	0.55		

R-IV THREE-WAY ANALYSIS OF VARIANCE ON THE MAXIMAL ISOMETRIC FORCE (P_o) AT AN ELBOW ANGLE OF 160°

SUMMARY TABLE

SOURCE	SS	DF	MS	F	P
Bet. Sub	438.80	41			
A	1.85	1	1.85	0.17	0.69
B	24.82	2	12.41	1.12	0.34
AB	12.24	2	6.12	0.55	0.58
Sub W Group	399.89	36	11.12		
Within Sub	21.73	42			
C	1.84	1	1.84	3.67	0.06
AC	0.36	1	0.36	0.71	0.41
BC	0.68	2	0.34	0.68	0.51
ABC	0.82	2	0.41	0.81	0.45
C X Sub W Group	18.04	36	0.50		

APPENDIX S

(CALIBRATION OF THE CYBEX II ISOKINETIC DYNAMOMETER)

APPENDIX S

The Cybex II Isokinetic Dynamometer was calibrated in accordance with the directions supplied by Lumex Inc. 100 Spence Street, BayShore, New York 11706. The procedure is as follows:

1) The desired recorder range scale was selected (0-30 or 0-180 ft lbs).

2) With the speed selector turned on at 5 revolutions per minute and the recorder turned on but no torque applied to the input shaft:

a. Position 4 was selected on the damping control.

b. The slow chart speed (2 mm/sec) was selected.

c. The stylus was aligned with the baseline of the chart paper grid using the zero adjustment control.

d. The range scale was changed in order to check for a baseline shift. Any shift in the baseline was corrected by adjusting the potentiometer with a screwdriver behind the cap marked zero on the front vertical panel of the recorder case.

3) The proper amount of disc weights were attached to the T bar as indicated below.

4) The dynamic calibration was done by manually lifting the weighted T bar to a vertical position above the dynamometer and allowing it to swing down until the weights contacted the floor. The specified torque is applied as the weighted arm passes the horizontal. The graph recording shows this value as the maximum point on the curve. If this point is above or below the correct torque value, the recorder was adjusted to make it read the correct value by turning the appropriate (30 or 180) potentiometer behind the plug on the front case of the

recorder using a small screwdriver.

Cybex Calibration

Scale	Lever Arm (inches)	Weight (lbs)	Torque (ft lbs)	Graph Recording (Peak)
180	31	32.5	90	5 major divisions
30	33	5	20	20 minor divisions